
SECTION 4

SURFACE SEDIMENT CHEMISTRY

On May 19, 20, and 21, 1993, the monitoring team collected surface sediment samples from the 3-foot cap, the ENR, and adjacent areas south of the remediation area. The samples were analyzed for trace metal, organic, and conventional parameters. This section describes the surface sampling methods, reports the results of the surface sample analysis, and compares the results to the state sediment standards, to the 1992 baseline study, and to the Denny Way sediment cap study.

METHODS

Within the remediation area, the monitoring plan defines seven surface sampling stations (VG1 through VG7). The stations provide spatial coverage across the area (Figure 4-1). VG3, VG4, and VG6 were placed along the centerline of the long axis of the rectangular-shaped ENR. VG5 was placed in the southeast corner of the remediation area on the shallower inshore end of the 3-foot cap. VG1, VG2, and VG7 provide sampling coverage of the 3-foot cap in deeper water.

Outside the remediation area, surface samples were taken at three stations (VG8, VG10, and VG11). These three stations were situated to monitor sediment conditions along the southern boundary of the remediation area.

Baseline sediment chemistry samples were collected from the seven stations in the remediation area and at VG8 in May 1992.

Sample Collection

Subtidal samples were collected with a 0.1-m² Van Veen grab sampler operated from Metro's *R V Liberty*. When possible, three individual grab samples were taken at each station. A "cookie cutter" sampler was used to remove a 2-cm-deep subsample from the top of each grab sample, and the three subsamples were composited in a 4-L beaker that had been cleaned in a muffle furnace at 932°F (500°C). A replicate sample was taken at VG1.

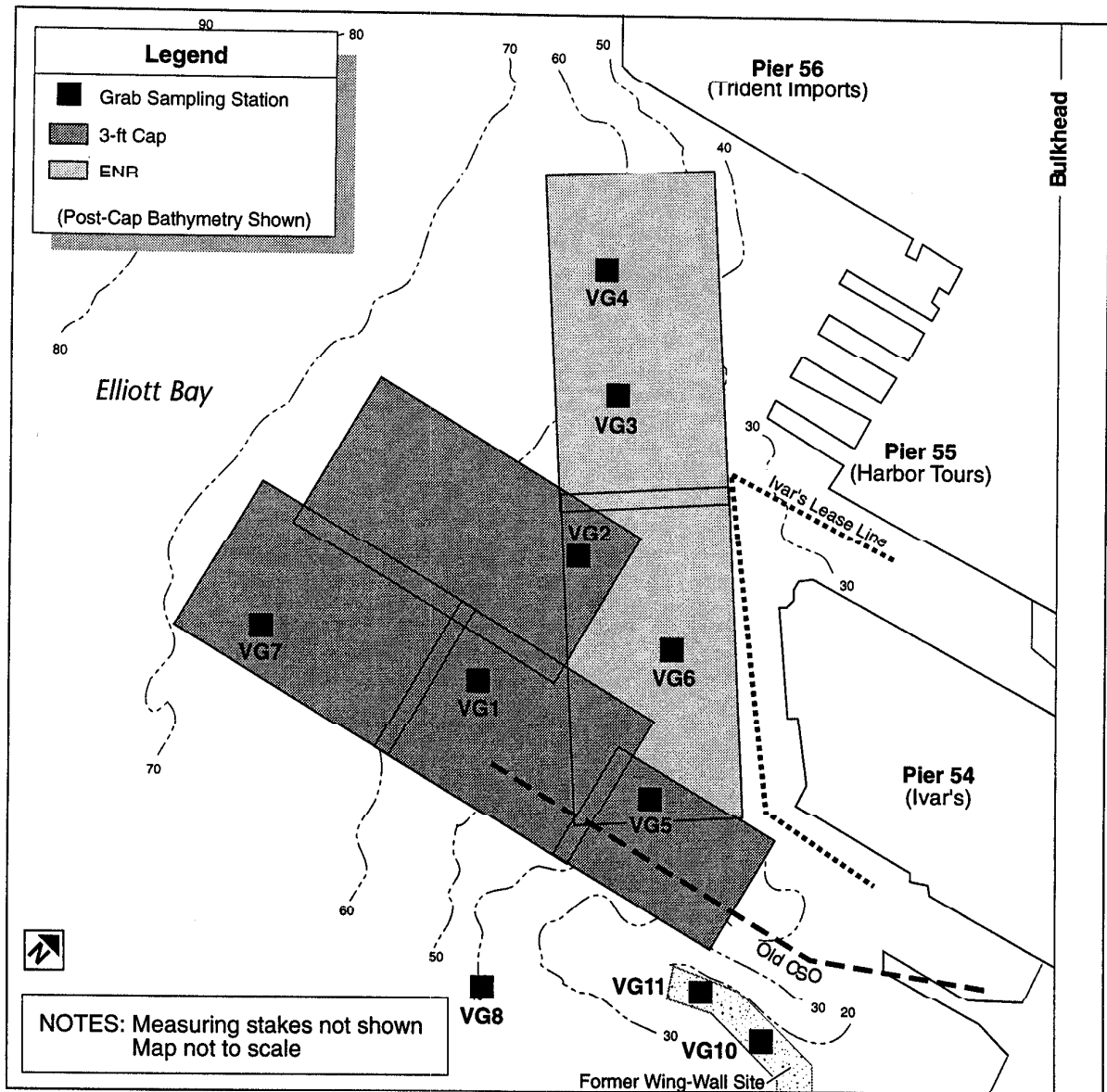


Figure 4-1. Surface Sampling Stations

Sample Analysis

The Metro Environmental Laboratory analyzed the samples for trace metals, BNAs, pesticides, PCBs, and volatile compounds. AmTest, Inc., analyzed the samples for particle size distribution, total solids, and total organic carbon. For complete results see Appendix D; for QA procedures see Appendix B.

RESULTS

Sampling Observations

During sampling at the southeast corner of the study area, the monitoring team discovered visible evidence of creosote contamination.

Inside the Remediation Area. Samples taken at VG5, the on-cap station closest to VG10 and VG11, contained small pieces of broken creosote-treated piles. Obvious pieces of pile were removed from the samples before the subsamples were taken. Oil droplets also appeared on the sediment surface as the water was drained from the samples.

Outside the Remediation Area. A thick black ooze was found on the surface of the sediments at VG10 and VG11. The ooze had the consistency of mayonnaise and had a very strong coal-tar creosote smell. The samples at VG10 were filled entirely with the black material. The samples at VG11 showed about a 2-inch-thick (5-cm) layer of the creosote material over the sand. After removing the top 2-cm subsamples, the excess sample material was placed in a 5-gallon (20-L) bucket and then poured back into the water at the station. As the excess material entered the water, it produced an oil slick that covered an area about 10 by 20 feet (3 m by 6 m).

Because of the discovery of creosote in the sediments at VG10 and VG11, the monitoring team decided to take additional samples at VG8 to compare analytical results to 1992 baseline analytical results. Three additional grab samples were taken, and the top 2-cm subsamples were composited into one sample. During sampling at VG8, the monitoring team observed that sediment conditions appeared similar to 1992 conditions. They did not find any pieces of piling, black creosote, or oil on the sediment.

Analytical Data

Data tables and figures appear at the end of this section. Data tables show detected chemicals on a dry-weight basis (Tables 4-1 through 4-5) and compared to the SMS (Tables 4-6 through 4-8). Figures show dry-weight chemical concentrations plotted on the cap (Figures 4-2 through 4-5). The results of the analysis of the surface samples show that after only 14 months, the entire 3-foot cap and ENR have been recontaminated and that concentrations of compounds found in the southeast half of the remediation area exceed the state sediment standards. The highest chemical concentrations were found outside the remediation area at VG10 and VG11.

Moving alongshore to the north and offshore to the west, the concentrations decreased consistently with distance from VG10 and VG11. VG5 showed the highest chemical concentrations of all stations within the remediation area. Farther away from VG10 and VG11, the next highest concentrations found within the remediation area were at VG1 and VG6. The lowest concentrations were found at the station farthest offshore (VG7); the second lowest concentrations were found at the station farthest north (VG4).

Inside the Remediation Area. In all, 20 compounds were detected inside the remediation area. Phenanthrene, fluoranthene, pyrene, chrysene, and benzo(b)fluoranthene were detected in the highest concentrations. Two volatile compounds were detected in concentrations close to the detection limits. The highest concentration of a single chemical was 30,000 µg/kg dry weight for phenanthrene at VG5. Station-specific comparisons with the SMS are as follows:

- **VG5.** Six LPAHs and total LPAHs exceeded the CSL. Benzo(a)anthracene, chrysene, dibenzofuran, and mercury also exceeded the CSL. Total LPAHs exceeded the CSL by more than three times. Four single HPAHs and total HPAHs exceeded the SQS.
- **VG1 Primary.** Total LPAHs were 47 percent, total IHPAHs were 30 percent, mercury was 50 percent, and zinc was 18 percent of the SQS. Acenaphthene exceeded the SQS.
- **VG1 Replicate.** Total LPAHs were 68 percent, total HPAHs were 53 percent, mercury was 25 percent, and zinc was 13 percent of the SQS. Phenanthrene, acenaphthene, fluoranthene, and dibenzofuran exceeded the SQS.
- **VG6.** Total LPAHs were 81 percent, total HPAHs were 55 percent, mercury was 50 percent, and zinc was 18 percent of the SQS.
- **VG2.** Total LPAHs were 40 percent, total HPAHs were 40 percent, mercury was 50 percent, and zinc was 19 percent of the SQS.
- **VG3.** Total LPAHs were 23 percent, total HPAHs were 28 percent, mercury was 25 percent, and zinc was 16 percent of the SQS.
- **VG4.** Total LPAH were 20 percent, total HPAHs were 20 percent, mercury was 25 percent, and zinc was 16 percent of the SQS.
- **VG7.** All parameters were around or below 10 percent of the SQS.

Outside the Remediation Area. Seventeen compounds were detected at the stations outside the remediation area. Four LPAHs (phenanthrene, naphthalene, acenaphthene, and fluorene) and two HPAHs (fluoranthene and pyrene) were found in the highest concentrations. The highest concentration of a single chemical was 90,000 µg/kg dry weight for phenanthrene at VG10. Station-specific comparisons with the SMS are as follows:

- **VG10.** Five LPAHs, total LPAHs, two HPAHs, dibenzofuran, mercury, and silver exceeded the CSL. Total LPAHs were almost seven times higher than the CSL. One LPAH, six HPAHs, total HPAHs, and lead exceeded the SQS.
- **VG11.** Five LPAHs, total LPAHs, dibenzofuran, mercury, and silver exceeded the CSL. Total LPAHs were almost four times higher than the CSL. Three HPAHs and total HPAHs exceeded the SQS.
- **VG8.** Three LPAHs, total LPAHs, three HPAHs, total HPAHs, and dibenzofuran exceeded the SQS.

DISCUSSION

Comparison to the 1992 Baseline Data

In 1992, nine organic compounds were detected within the remediation area. In 1993, the number more than doubled to 20 compounds and concentrations of all previously detected compounds increased significantly. The newly detected compounds were naphthalene, acenaphthene, acenaphthylene, fluorene, and 2-methylnaphthalene—which are all LPAHs—and benzo(g,h,i) perylene, benzoic acid, carbazole, dibenzofuran, 1,1,2,2-tetrachloroethane, and acetone.

Concentration increases in 1993 of compounds detected in 1992 were highest at the southeast end of the remediation area, steadily decreasing moving alongshore to the north and offshore to the west. Station-specific ranges of increase are as follows:

- **VG5.** Increases ranged from 248 times higher for phenanthrene to 41 times higher for benzo(b)fluoranthene.
- **VG6.** Increases ranged from 87 times higher for phenanthrene to 29 times higher for benzo(a)pyrene.

- **VG1.** Increases ranged from 193 times higher for phenanthrene to 18 times higher for benzo(b)fluoranthene.
- **VG1r.** Increases ranged from 170 times higher for phenanthrene to 16 times higher for benzo(b)fluoranthene.
- **VG4.** Increases ranged from 10 times higher for fluoranthene to 6 times higher for pyrene.
- **VG7.** Increases ranged from 11 times higher for chrysene to 7 times higher for pyrene.

Several other studies that were also conducted along the waterfront have shown that concentrations decrease with distance offshore (Malins et al., 1980; Romberg et al., 1984; Tetra Tech, Inc., 1988; Metro, 1988, 1989).

Comparison to the Denny Way Sediment Cap

The Denny Way sediment cap, located north of Seattle's downtown waterfront, was installed in 1990 approximately 150 feet offshore of the Denny Way CSO, which is the largest CSO in Puget Sound. Contaminated sediments inshore of the capping area were not remediated. For this reason and because source control measures were not yet complete, a plan was developed to monitor possible recontamination on the surface of the cap from CSOs and inshore sediments. The surface of the cap was sampled in 1990, 1991, and 1992, and chemical trends were evaluated. The samples showed that chemical concentrations increased each year. A comparison of all surface stations during all three sampling events showed that the station closest to shore and closest to the CSO (Station K) had the highest concentrations.

Comparing sampling results in mg/kg dry weight from Station K in 1992 (2 years after capping at the Denny Way site) to VG5 (14 months after capping at the Pier 53 site) shows that total LPAHs were 114 times higher and total HPAHs were 34 times higher at VG5 than at Station K. Comparing total LPAH and HPAH concentrations at Station K to the other stations in the Pier 53 remediation area shows that concentrations from six of the seven Pier 53 stations are higher than the highest Station K values. Only VG7, the station farthest offshore on the Pier 53 cap, had lower concentrations than Station K.

Source of Recontamination of the Pier 53 Remediation Area

The recontamination of the Pier 53 remediation area may have been caused by a few sources, some of which remain unknown without further study. Three possible sources are the removal of the auxiliary ferry dock wing wall, the Madison Street CSO, and wave action redistributing contaminated nearshore sediments.

The recontamination of the Pier 53 remediation area was not likely caused by the Madison Street CSO or wave action redistributing contaminated nearshore sediments. In 1993, sediments at Pier 53 showed very high LPAH concentrations when compared to HPAH concentrations. If the contamination came from the Madison Street CSO or nearshore sediments, similar contamination would most likely have also been found on the Denny Way cap and in previous studies of nearshore sediments in the Pier 53 area. Studies of the Denny Way sediment cap and of sediments under Piers 54 and 55 (Metro, 1993), however, showed much lower overall concentrations and higher HPAH concentrations than LPAH concentrations. The high relative LPAH concentrations at the Pier 53 site are distinctly different from the sediment chemical makeup at the Denny Way cap and in the sediments inshore of the Pier 53 remediation area. The concentrations of organic chemicals are also much lower on the Denny Way cap, even though the Denny Way CSO discharges a much greater volume than the Madison Street CSO and the elapsed time since capping has been longer at Denny Way.

It is significant that the data from the Pier 53 area show much higher concentrations of LPAHs than of other organic compounds. At VG5, VG10, and VG11, LPAHs exceeded the CSL a total of 17 times compared to 5 times for all other organic chemicals at these stations. The LPAHs that exceeded the CSL were naphthalene, acenaphthene, phenanthrene, anthracene, fluorene, and 2-methylnaphthalene. All of these are found in coal tar (Merck, 1976).

It is possible that the source of the LPAHs is coal-tar creosote, which is used to coat and protect wood piles in the marine environment. Up until early 1993, an auxiliary ferry terminal loading ramp wing wall, constructed of about 400 wood piles, was located about 150 feet south of VG5. The wing wall was part of the auxiliary ferry terminal loading slip located on the north side of the downtown Seattle ferry terminal. The wood piles were removed by a contractor hired by WSDOT. The contractor used a crane barge with a clamshell bucket to pull the piles out of the bay bottom. (To remove piles that are broken off at the bottom surface, contractors typically dig into the bottom with the clamshell bucket.)

During the service life of the wing wall, it is possible that a large amount of creosote sloughed off the piles and settled in the sediments at the base of the piles. When the wing wall was removed, these creosote-contaminated sediments were stirred up into the water column and resettled onto a broad area surrounding the site.

It is also possible that the construction activities stirred up deeper contamination. Recent sediment core samples collected for WSDOT near the ferry terminal showed that PAH concentrations exceeded the sediment standards in sediments from the surface down to a depth of 20 feet (6.1 m) (Hart-Crowser, Inc., 1994). This contamination is apparently from historical waterfront activities such as spillage from coal shipping and storage.

It is interesting that VG8 is approximately the same distance from the former wing-wall site as VG5, yet the concentrations of organics were much higher at VG5 and even at VG6 than at VG8. The monitoring team noted during sampling that the VG8 samples looked similar to those taken at VG8 the previous year, and this observation was consistent with the analytical results.

VG8 is located southwest of the former wing wall, and VG5 is located northwest. A study of the local currents at the Pier 53 site in February 1992 showed that the prevailing currents were to the north-northeast and were associated with an incoming tide (Metro, 1993). It is possible that the wing-wall demolition occurred during an incoming tide so that sediment suspended in the water column drifted north with the current toward VG5 and away from VG8.

Another possibility is that propeller wash from docking ferries could have prevented contaminated sediments from settling at VG8.

Also, bathymetry of the wing-wall area shows that both VG5 and VG8 are in deeper water than the wing-wall site. Sediments settling out of the water column will more likely travel in the downhill direction. In addition, a valley-like depression adjacent to the wing-wall area could have funneled settling sediments toward VG5 on the southeast corner of the cap. VG8 is situated on a ridge area of the bottom where suspended sediments from the wing-wall site might be less likely to settle.

There is a strong correlation between the demolition of the ferry terminal wing wall, the discovery of coal-tar creosote in the sediment samples, and the results of the sediment chemistry analysis of the samples from the southeast section of the Pier 53 study area.

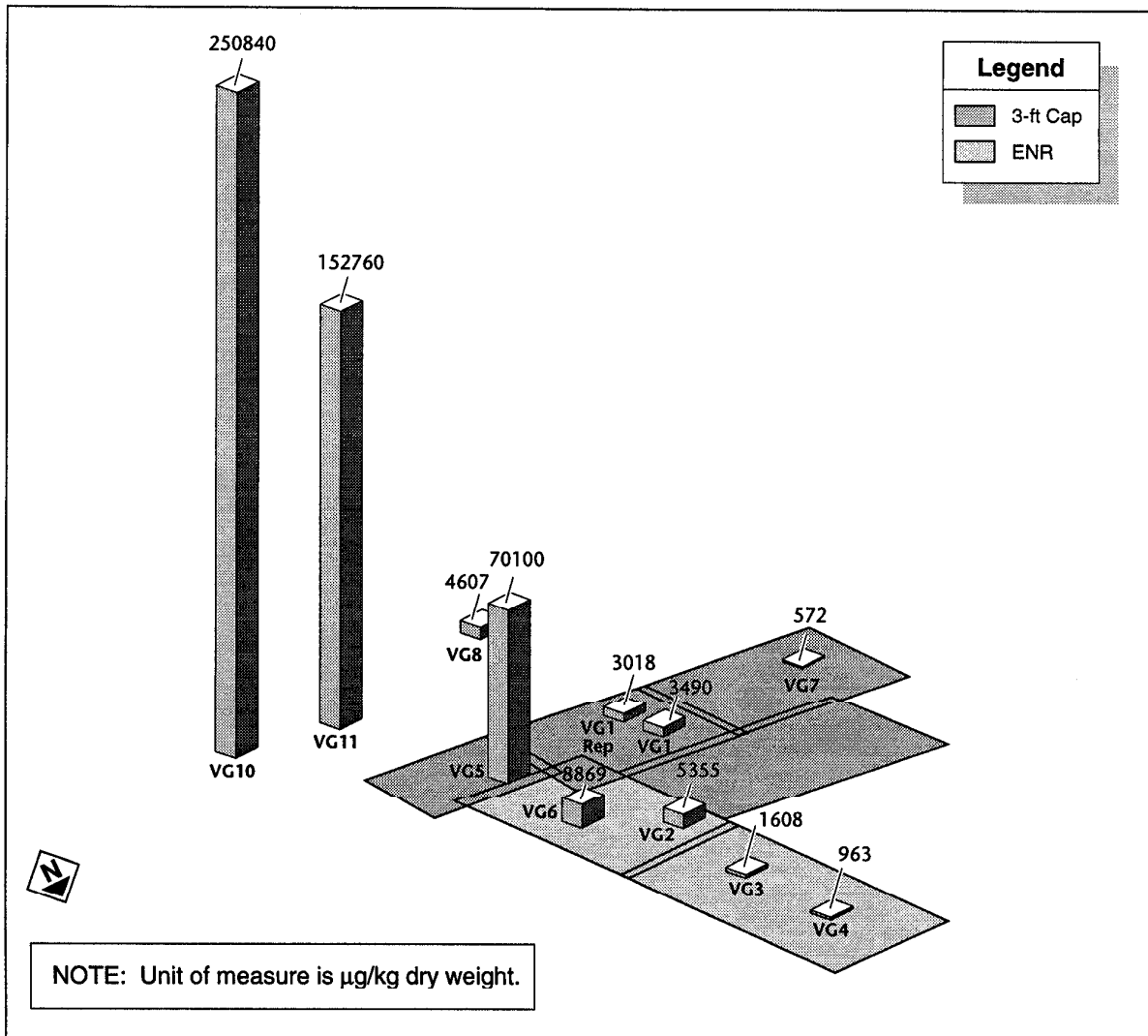


Figure 4-2. Spatial Concentrations of Total LPAHs

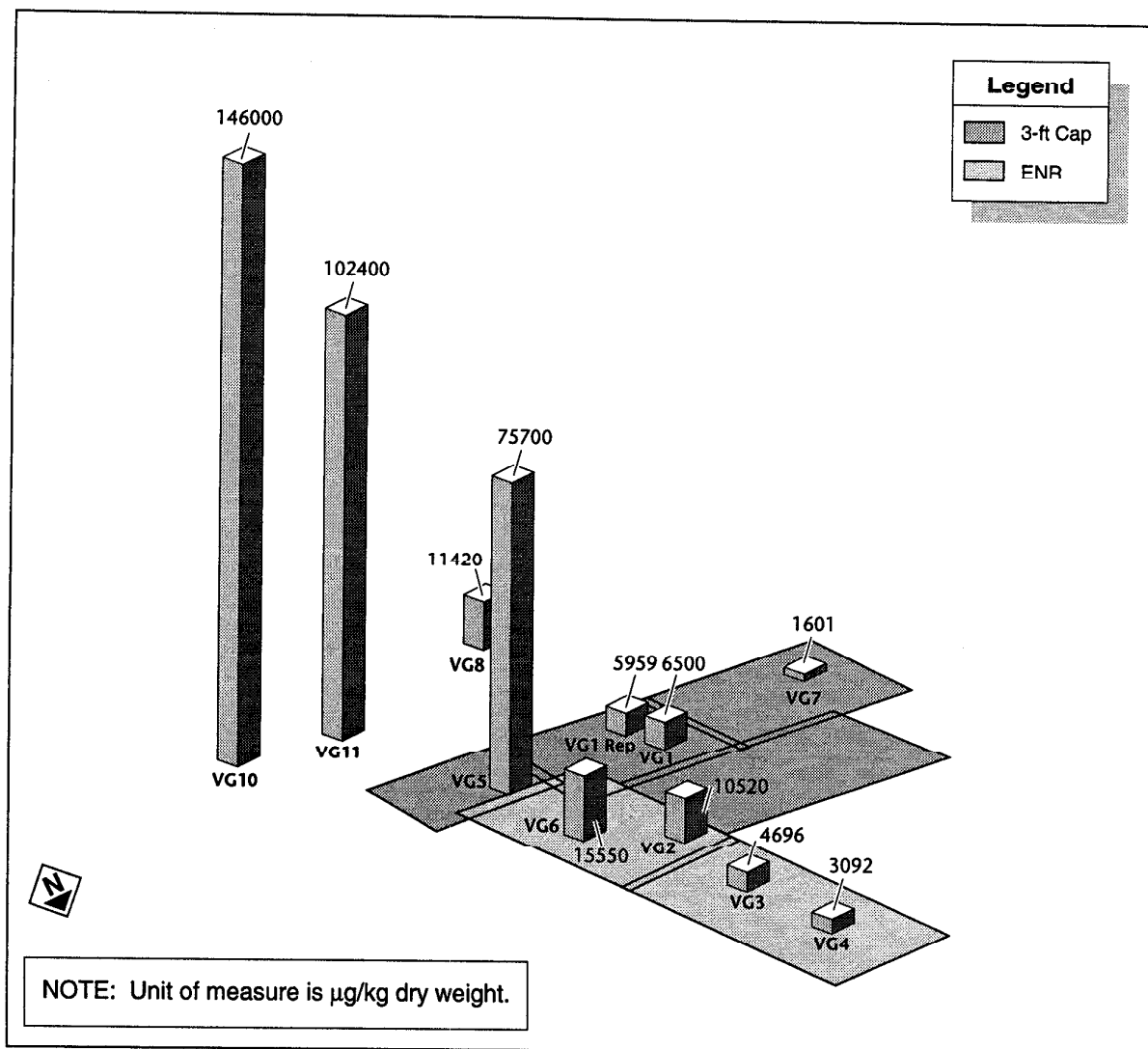


Figure 4-3. Spatial Concentrations of Total HPAHs

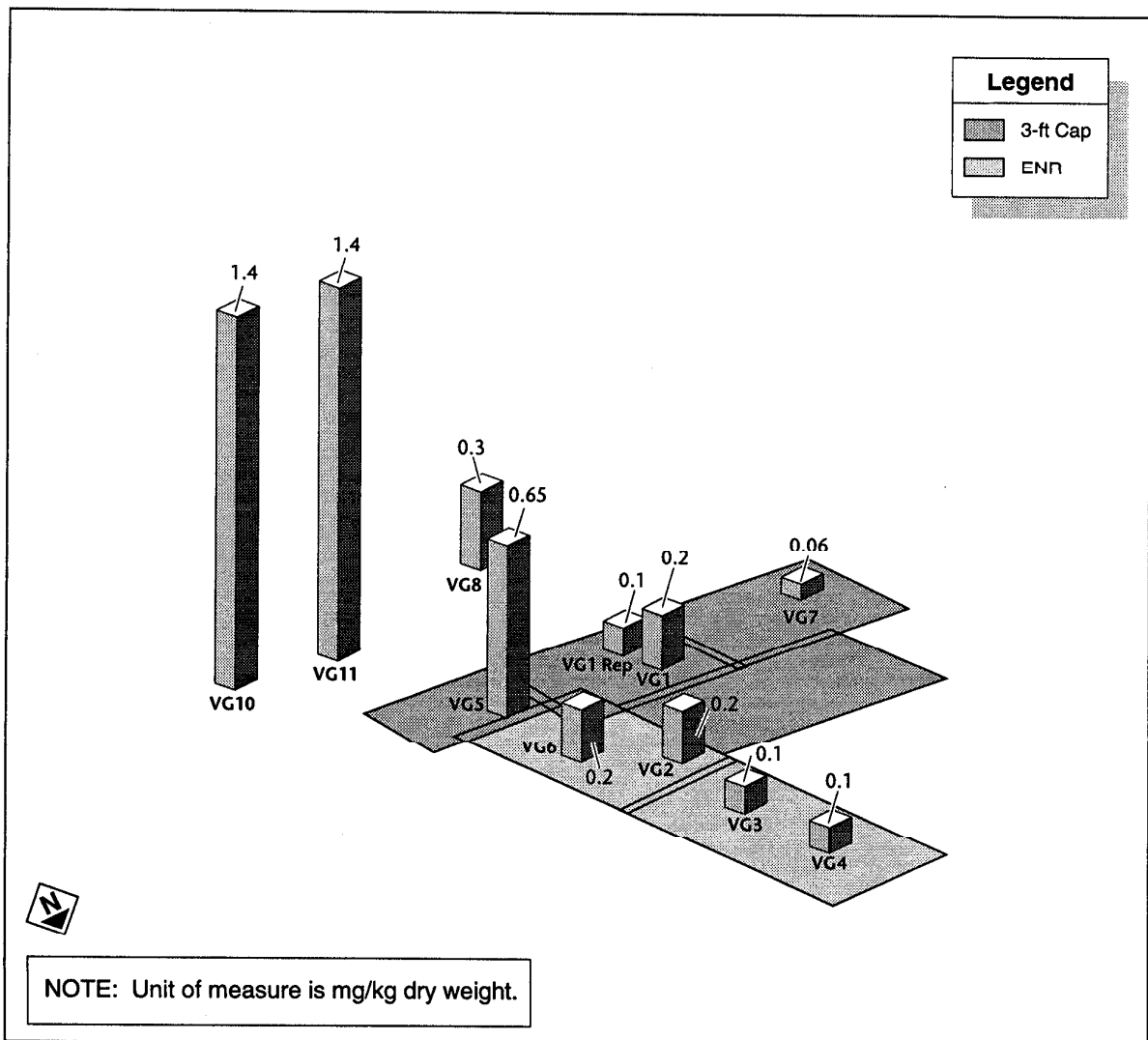


Figure 4-4. Spatial Concentrations of Mercury

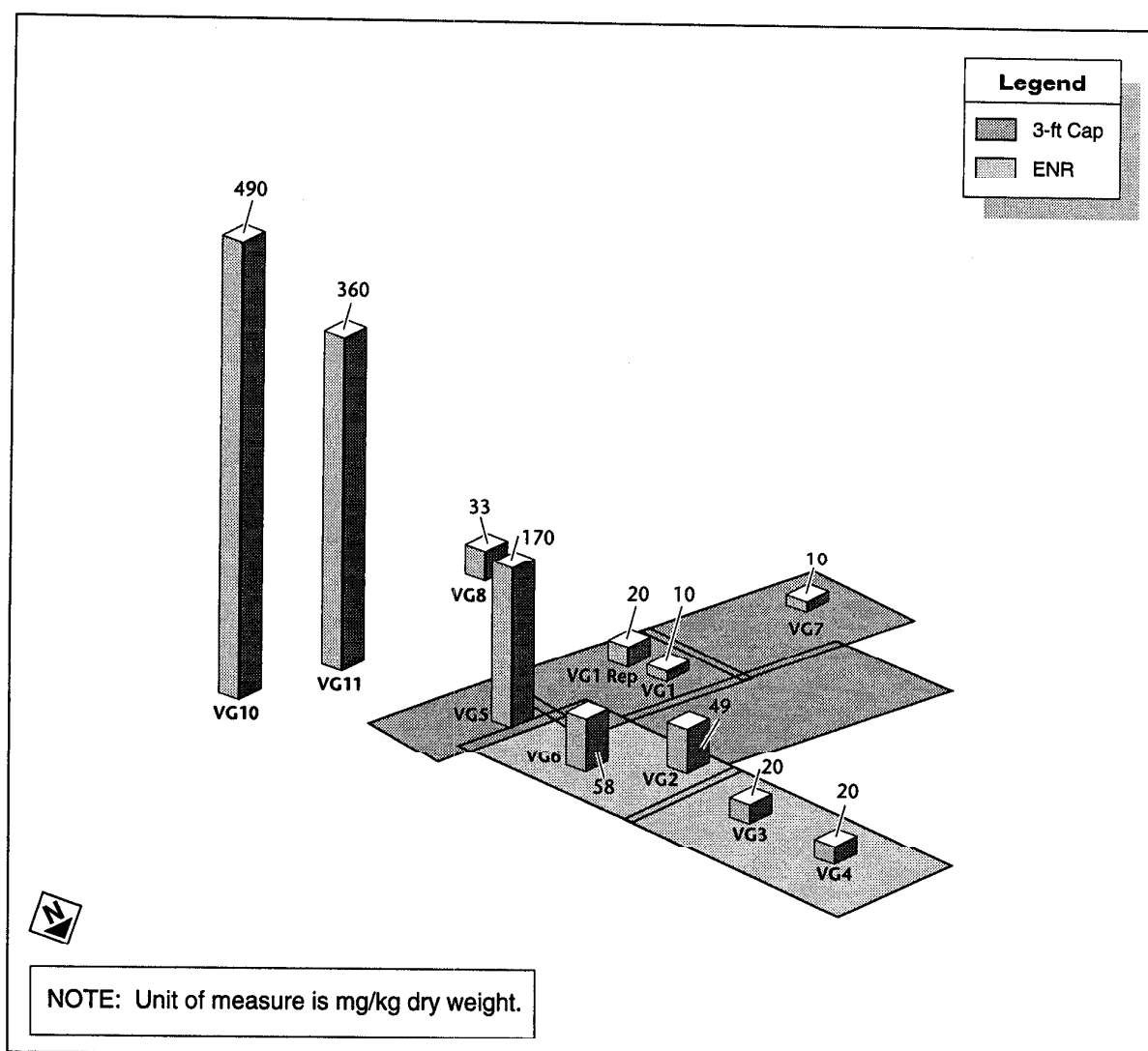


Figure 4-5. Spatial Concentrations of Lead

TABLE 4-1. Surface Station VG1, Detected Chemicals

Station	VG1				VG1 Replicate			
Date	May 20, 93				May 20, 93			
Sample Number	L1145-1				L1145-2			
% Solids	57				70			
% Total Organic Carbon	2.3				1.2			
BNA Organics (µg/kg dry weight)								
LPAHs	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
Naphthalene	210		50	88	170		40	71
Acenaphthene	370		10	23	330		10	19
Acenaphthylene	40		20	30	37		10	24
Anthracene	390		20	30	310		10	24
Fluorene	490		20	30	400		10	24
Phenanthrene	1900		20	30	1700		10	24
2-Methylnaphthalene	90	<RDL	50	88	71	<RDL	40	71
Total LPAH	3490				3018			
HPAHs								
Fluoranthene	2600		20	35	2300		10	29
Pyrene	1200		20	30	1000		10	24
Benzo(a)anthracene	580		20	30	610		10	24
Chrysene	630		20	30	660		10	24
Benzo(b)fluoranthene	740		50	88	660		40	71
Benzo(k)fluoranthene	250		50	88	310		40	71
Benzo(a)pyrene	370		40	58	340		30	47
Benzo(g,h,i)perylene	130		40	58	79		30	47
Total HPAH	6500				5959			
Other BNAs								
Benzoic Acid	420		100	170	270		100	140
Carbazole	100		40	58	91		30	47
Dibenzofuran	320		40	58	270		30	47
Volatiles (µg/kg dry weight)								
1,1,2,2-Tetrachloroethane		<MDL	9	18		<MDL	7	14
Acetone		<MDL	50	88		<MDL	40	71
Metals (mg/kg dry weight)								
Mercury	0.2	<RDL,E	0.04	0.35	0.1	<RDL,E	0.03	0.29
Aluminum	14000		20	86	11000		10	66
Antimony		<MDL,G	9	46		<MDL,G	6	29
Arsenic	10	<RDL	9	44	9	<RDL	7	33
Beryllium	0.5	<RDL	0.2	0.86	0.4	<RDL	0.1	0.66
Cadmium		<MDL,L	0.9	4.6	0.6	<RDL,L	0.6	2.9
Chromium	23		0.9	4.4	16		0.7	3.3
Copper	46		1	6.1	24		0.9	3.7
Iron	26000		9	44	20000		7	33
Lead	20	<RDL	5	26	10	<RDL	4	20
Nickel	18		4	17	14		3	13
Selenium		<MDL	9	44		<MDL	7	33
Silver	0.9	<RDL	0.7	3.5	0.6	<RDL	0.6	2.6
Zinc	75		0.9	4.4	54		0.7	3.3

<MDL - Undetected at the method detection limit

<RDL - Detected below reporting detection limits

B - Blank contamination

E - Estimate

G - Low standard reference material recovery

L - High standard reference material recovery

Note: For further information on data qualifiers see Appendix B.

TABLE 4-2. Surface Stations VG2 and VG3, Detected Chemicals

Station	VG2				VG3			
Date	May 20, 93				May 19, 93			
Sample Number	L1145-3				L1145-4			
% Solids	57				65			
% Total Organic Carbon	3.5				1.8			
BNA Organics (µg/kg dry weight)	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
LPAHs								
Naphthalene	210		50	88	83		50	77
Acenaphthene	560		10	23	130		10	20
Acenaphthylene	65		20	30	35		20	26
Anthracene	530		20	30	290		20	26
Fluorene	700		20	30	170		20	26
Phenanthrene	3200		20	30	850		20	26
2-Methylnaphthalene	90	<RDL	50	88		<MDL	50	77
Total LPAH	5355				1608			
HPAHs								
Fluoranthene	3700		20	35	1500		20	31
Pyrene	1700		20	30	680		20	26
Benzo(a)anthracene	1200		20	30	570		20	26
Chrysene	1200		20	30	600		20	26
Benzo(b)fluoranthene	1400		50	88	720		50	77
Benzo(k)fluoranthene	490		50	88	200		50	77
Benzo(a)pyrene	670		40	58	340		30	51
Benzo(g,h,i)perylene	160		40	58	86		30	51
Total HPAH	10520				4696			
Other BNAs								
Benzoic Acid		<MDL	100	180	290		100	150
Carbazole	140		40	58	62		30	51
Dibenzofuran	420		40	58	110		30	51
Volatiles (µg/kg dry weight)								
1,1,2,2-Tetrachloroethane	9	<RDL	9	18		<MDL	8	15
Acetone	150		50	88	110		50	77
Metals (mg/kg dry weight)								
Mercury	0.2	<RDL,E	0.04	0.35	0.1	<RDL,E	0.03	0.31
Aluminum	15000		20	82	13000		20	74
Antimony		<MDL,G	9	44		<MDL,G	8	34
Arsenic	20	<RDL	9	42	10	<RDL	8	37
Beryllium	0.5	<RDL	0.2	0.82	0.5	<RDL	0.2	0.74
Cadmium	0.9	<RDL,L	0.9	4.4		<MDL,L	0.8	3.4
Chromium	21		0.9	4.2	18		0.8	3.7
Copper	53		1	5.8	35		0.9	4.5
Iron	26000		9	42	22000		8	37
Lead	49		9	44	20	<RDL	5	22
Nickel	17		4	16	10	<RDL	3	15
Selenium		<MDL	9	42		<MDL	8	37
Silver	0.7	<RDL	0.7	3.3		<MDL	0.6	2.9
Zinc	79		0.9	4.2	65		0.8	3.7

<MDL - Undetected at the method detection limit

<RDL - Detected below reporting detection limits

B - Blank contamination

E - Estimate

G - Low standard reference material recovery

L - High standard reference material recovery

Note: For further information on data qualifiers see Appendix B.

TABLE 4-3. Surface Stations VG4 and VG5, Detected Chemicals

Station	VG4				VG5			
Date	May 19, 93				May 21, 93			
Sample Number	L1145-5				L1145-6			
% Solids	69				57			
% Total Organic Carbon	1.6				2.6			
BNA Organics (µg/kg dry weight)	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
LPAHs								
Naphthalene		<MDL	40	72	9500		500	880
Acenaphthene	83		10	19	10000		100	230
Acenaphthylene	20		10	25		<MDL	200	300
Anthracene	190		10	25	6000		200	300
Fluorene	110		10	25	10000		200	300
Phenanthrene	480		10	25	30000		200	300
2-Methylnaphthalene		<MDL	40	72	4400		500	880
Total LPAH	963				70100			
HPAHs								
Fluoranthene	860		10	29	26000		200	350
Pyrene	420		10	25	21000		200	300
Benzo(a)anthracene	360		10	25	8200		200	300
Chrysene	480		10	25	10000		200	300
Benzo(b)fluoranthene	510		40	72	4600		500	880
Benzo(k)fluoranthene	140		40	72	1800		500	880
Benzo(a)pyrene	250		30	48	3000		400	580
Benzo(g,h,i)perylene	72		30	48	1100		400	580
Total HPAH	3092				75700			
Other BNAs								
Benzoic Acid		<MDL	100	140		<MDL	1000	1800
Carbazole	40	<RDL	30	48	1400		400	580
Dibenzofuran	62		30	48	6800		400	580
Volatiles (µg/kg dry weight)								
1,1,2,2-Tetrachloroethane		<MDL	7	14		<MDL	9	18
Acetone		<MDL	40	72		<MDL	50	88
Metals (mg/kg dry weight)								
Mercury	0.1	<RDL,E	0.03	0.29	0.65	E	0.04	0.35
Aluminum	14000		7	35	13000		20	84
Antimony	4	<RDL,G	1	14		<MDL,G	9	44
Arsenic	10	<RDL	3	17	10	<RDL	9	42
Beryllium	0.48		0.07	0.35	0.5	<RDL	0.2	0.84
Cadmium	0.4	<RDL,L	0.1	1.4	2	<RDL,L	0.9	4.4
Chromium	19		0.3	1.7	37		0.9	4.2
Copper	32		0.4	2	89		1	5.8
Iron	23000		3	17	25000		9	42
Lead	20		1	14	170		9	44
Nickel	16		1	7	30		4	17
Selenium	4	<RDL	3	17		<MDL	9	42
Silver	0.7	<RDL	0.3	1.4	3.5	<RDL	0.7	3.3
Zinc	65		0.3	1.7	160		0.9	4.2

<MDL - Undetected at the method detection limit

<RDL - Detected below reporting detection limits

B - Blank contamination

E - Estimate

G - Low standard reference material recovery

L - High standard reference material recovery

Note: For further information on data qualifiers see Appendix B.

TABLE 4-4. Surface Stations VG6 and VG7, Detected Chemicals

Station	VG6				VG7			
Date	May 21, 93				May 21, 93			
Sample Number	L1145-7				L1145-8			
% Solids	57				72			
% Total Organic Carbon	3				1.1			
BNA Organics (µg/kg dry weight)	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
LPAHs								
Naphthalene	370		50	88	<MDL		40	68
Acenaphthene	1000		10	23	42		10	18
Acenaphthylene	89		20	30	<MDL		10	22
Anthracene	1100		20	30	100		10	22
Fluorene	1200		20	30	60		10	22
Phenanthrene	4900		20	30	280		10	22
2-Methylnaphthalene	210		50	88	<MDL		40	68
Total LPAH	8869				572			
HPAHs								
Fluoranthene	5400		20	35	500		10	28
Pyrene	3000		20	30	240		10	22
Benzo(a)anthracene	1700		20	30	170		10	22
Chrysene	1800		20	30	220		10	22
Benzo(b)fluoranthene	1900		50	88	250		40	68
Benzo(k)fluoranthene	670		50	88	81		40	68
Benzo(a)pyrene	890		40	58	110		30	46
Benzo(g,h,i)perylene	190		40	58	<MDL		30	46
Total HPAH	15550				1601			
Other BNAs								
Benzoic Acid		<MDL	100	180		<MDL	100	140
Carbazole	280		40	58		<MDL	30	46
Dibenzofuran	790		40	58	30	<RDL	30	46
Volatiles (µg/kg dry weight)								
1,1,2,2-Tetrachloroethane		<MDL	9	18		<MDL	7	14
Acetone		<MDL	50	88		<MDL	40	69
Metals (mg/kg dry weight)								
Mercury	0.2	<RDL,E	0.04	0.35	0.06	<RDL,E	0.03	0.28
Aluminum	13000		20	88	9900		10	68
Antimony		<MDL,G	9	46		<MDL,G	6	29
Arsenic	10	<RDL	9	44	8	<RDL	7	35
Beryllium	0.4	<RDL	0.2	0.88	0.3	<RDL	0.1	0.68
Cadmium		<MDL,L	0.9	4.6		<MDL,L	0.6	2.9
Chromium	19		0.9	4.4	14		0.7	3.5
Copper	56		1	6.1	21		0.8	3.9
Iron	23000		9	44	19000		7	35
Lead	58		9	46	10	<RDL	4	21
Nickel	20	<RDL	4	17	10	<RDL	3	14
Selenium		<MDL	9	44		<MDL	7	35
Silver	0.9	<RDL	0.7	3.5		<MDL	0.6	2.8
Zinc	82		0.9	4.4	51		0.7	3.5

<MDL - Undetected at the method detection limit

<RDL - Detected below reporting detection limits

B - Blank contamination

Note: For further information on data qualifiers see Appendix B.

E - Estimate

G - Low standard reference material recovery

L - High standard reference material recovery

TABLE 4-5. Surface Stations VG8, VG10, and VG11, Detected Chemicals

Station	P53VG8				P53VG10				P53VG11			
Date	May 21, 93				May 21, 93				May 21, 93			
Sample Number	L1145-12				L1145-9				L1145-10			
% Solids	70				51				58			
% Total Organic Carbon	0.99				4.7				5.2			
BNA Organics (µg/kg dry weight)	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
LPAHs												
Naphthalene	100		40	70	51000		600	980	38000		500	860
Acenaphthene	290		10	19	39000		100	250	21000		100	220
Acenaphthylene	76		10	23	840		200	330	660		200	290
Anthracene	590		10	23	11000		200	330	8100		200	290
Fluorene	570		10	23	35000		200	330	19000		200	290
Phenanthrene	2900		10	23	90000		200	330	53000		200	290
2-Methylnaphthalene	81		40	70	24000		600	980	13000		500	860
Total LPAH	4607				250840				152760			
HPAHs												
Fluoranthene	3400		10	29	57000		200	390	36000		200	340
Pyrene	1900		10	23	41000		200	330	29000		200	290
Benzo(a)anthracene	1400		10	23	15000		200	330	11000		200	290
Chrysene	1600		10	23	14000		200	330	11000		200	290
Benzo(b)fluoranthene	1600		40	70	8600		600	980	6700		500	860
Benzo(k)fluoranthene	630		40	70	3300		600	980	3100		500	860
Benzo(a)pyrene	770		30	47	5300		400	650	4500		300	570
Benzo(g,h,i)perylene	120		30	47	1800		400	650	1100		300	570
Total HPAH	11420				146000				102400			
Other BNAs												
Benzoic Acid		<MDL	100	140		<MDL	1000	2000		<MDL	1000	1700
Carbazole	170		30	47	5900		400	650	3300		300	570
Dibenzofuran	270		30	47	25000		400	650	14000		300	570
Volatiles (µg/kg dry weight)												
1,1,2,2-Tetrachloroethane		<MDL	7	14		<MDL	10	20		<MDL	9	17
Acetone		<MDL	40	71		<MDL	60	98		<MDL	50	86
Metals (mg/kg dry weight)												
Mercury	0.3	<RDL,E	0	0.3	1.4	E	0	0.4	1.4	E	0	0.3
Aluminum	11000		10	69	15000		20	98	13000		20	84
Antimony		<MDL,G	6	29		<MDL,G	10	57		<MDL,G	9	45
Arsenic	10	<RDL	7	34	20	<RDL	10	49	20	<RDL	9	41
Beryllium	0.4	<RDL	0.1	0.7	0.6	<RDL	0.2	1	0.3	<RDL	0.2	0.8
Cadmium	0.9	<RDL,L	0.6	2.9	4	<RDL,L	1	5.7	3	<RDL,L	0.9	4.5
Chromium	20		0.7	3.4	51		1	4.9	40		0.9	4.1
Copper	34		0.9	3.9	180		2	7.6	130		1	5.7
Iron	20000		7	34	24000		10	49	21000		9	41
Lead	33		6	29	490		10	57	360		9	45
Nickel	19		3	14	45		4	19	38		3	17
Selenium		<MDL	7	34		<MDL	10	49		<MDL	9	41
Silver	0.7	<RDL	0.6	2.7	10		2	7.6	6.2		1	5.7
Zinc	64		0.7	3.4	220		1	4.9	190		0.9	4.1

<MDL - Undetected at the method detection limit

<RDL - Detected below reporting detection limits

B - Blank contamination

E - Estimate

G - Low standard reference material recovery

L - High standard reference material recovery

Note: For further information on data qualifiers see Appendix B.

TABLE 4-6. Stations VG1, VG2, and VG3, Comparison to Standards

Station	VC1		VG1 Replicate		VG2		VG3		Sediment Management Standards	
Date	May 20, 93		May 20, 93		May 20, 93		May 19, 93			
Sample Number	L1145-1		L1145-2		L1145-3		L1145-4			
% Solids	57		70		57		65			
% Total Organic Carbon	2.3		1.2		3.5		1.8		SQS Table I	CSL Table III
Organics										
LPAHs (mg/kg TOC)	Value	Qual	Value	Qual	Value	Qual	Value	Qual		
Naphthalene	9.1		14		6		4.6		99	170
Acenaphthylene	1.7		3.1		1.9		1.9		66	66
Acenaphthene	16*		27*		16*		7.2		16	57
Fluorene	21		33		20		9.4		23	79
Phenanthrene	83		140*		91		47		100	480
Anthracene	17		26		15		16		220	1200
2-Methylnaphthalene	3.9	<RDL	5.9	<RDL	2.6	<RDL	2.8	<MDL	38	64
Total LPAHs	151.7		249		152.5		88.9		370	780
HPAHs (mg/kg TOC)										
Fluoranthene	110		190*		110		83		160	1200
Pyrene	52		83		49		37		1000	1400
Benzo(a)anthracene	25		51		34		32		110	270
Chrysene	27		55		34		33		110	460
Total benzofluoranthenes	43		81		54		51		230	450
Benzo(a)pyrene	16		28		19		19		99	210
Indeno(1,2,3-Cd)Pyrene	6.1		9.2		4.9		6.7		34	88
Dibenzo(a,h)anthracene	2.2	<MDL	3.3	<MDL	1.4	<MDL	2.8	<MDL	12	33
Benzo(g,h,i)perylene	5.7		6.6		4.6		4.8		31	78
Total HPAHs	287		507.1		310.9		269.3		960	5300
Other (mg/kg TOC)										
1,2-Dichlorobenzene	0.87	<MDL	0.83	<MDL	0.57	<MDL	1.1	<MDL	2.3	2.3
1,4-Dichlorobenzene	0.87	<MDL	0.83	<MDL	0.57	<MDL	1.1	<MDL	3.1	9
1,2,4-Trichlorobenzene	0.87*	<MDL	0.83*	<MDL	0.57	<MDL	1.1*	<MDL	0.81	1.8
Hexachlorobenzene	0.87*	<MDL	0.83*	<MDL	0.57	<MDL	1.1*	<MDL	0.38	2.3
Diethyl Phthalate	1.7	<MDL	2.5	<MDL	1.1	<MDL	1.7	<MDL	61	110
Dimethyl Phthalate	0.43	<MDL	0.83	<MDL	0.28	<MDL	0.56	<MDL	53	53
Di-N-Butyl Phthalate	1.7	<MDL	2.5	<MDL	1.1	<MDL	1.7	<MDL	220	1700
Benzyl Butyl Phthalate	0.87	<MDL	0.83	<MDL	0.57	<MDL	1.1	<MDL	4.9	64
Bis(2-Ethylhexyl)Phthalate	0.87	<MDL,B	0.83	<MDL,B	0.57	<MDL,B	1.1	<MDL,B	47	78
Di-N-Octyl Phthalate	0.87	<MDL	0.83	<MDL	0.57	<MDL	1.1	<MDL	58	4500
Dibenzofuran	14		22*		12		6.1		15	58
Hexachlorobutadiene	1.7	<MDL	2.5	<MDL	1.1	<MDL	1.7	<MDL	3.9	6.2
N-Nitrosodiphenylamine	1.7	<MDL	2.5	<MDL	1.1	<MDL	1.7	<MDL	11	11
Total PCBs	0.43	<MDL	0.83	<MDL	0.28	<MDL	0.56	<MDL	12	65
Other (µg/kg dry weight)										
Phenol	100	<MDL	100	<MDL	100	<MDL	100	<MDL	420	1200
2-Methylphenol	40	<MDL	30	<MDL	40	<MDL	30	<MDL	63	63
4-Methylphenol	40	<MDL	30	<MDL	40	<MDL	30	<MDL	670	670
2,4-Dimethylphenol	40*	<MDL	30*	<MDL	40*	<MDL	30*	<MDL	29	29
Pentachlorophenol	40	<MDL	30	<MDL	40	<MDL	30	<MDL	360	690
Benzyl Alcohol	40	<MDL	30	<MDL	40	<MDL	30	<MDL	57	73
Benzoic Acid	420		270		100	<MDL	290		650	650
Metals (mg/kg dry weight)										
Mercury	0.2	<RDL,E	0.1	<RDL,E	0.2	<RDL,E	0.1	<RDL,E	0.41	0.59
Arsenic	10	<RDL	9	<RDL	20	<RDL	10	<RDL	57	93
Cadmium	0.9	<MDL,L	0.6	<RDL,L	0.9	<RDL,L	0.8	<MDL,L	5.1	6.7
Chromium	23		16		21		18		260	270
Copper	46		24		53		35		390	390
Lead	20	<RDL	10	<RDL	49		20	<RDL	450	530
Silver	0.9	<RDL	0.6	<RDL	0.7	<RDL	0.6	<MDL	6.1	6.1
Zinc	75		54		79		65		410	960

* - Exceeds SQS

<MDL - Undetected at the method detection limit

<RDL - Detected below reporting detection limits

B - Blank contamination

Note: For further information on data qualifiers see Appendix B.

** - Exceeds CSL

E - Estimate

G - Low standard reference material recovery

L - High standard reference material recovery

TABLE 4-7. Stations VG4, VG5, VG6 and VG7, Comparison to Standards

Station	VG4		VG5		VG6		VG7		Sediment Management Standards	
Date	May 19, 93		May 21, 93		May 21, 93		May 21, 93			
Sample Number	L1145-5		L1145-6		L1145-7		L1145-8			
% Solids	69		57		57		72			
% Total Organic Carbon	1.6		2.6		3		1.1			
Organics									SQS Table I	CSL Table III
LPAHs (mg/kg TOC)	Value	Qual	Value	Qual	Value	Qual	Value	Qual		
Naphthalene	2.5	<MDL	370**		12		3.6	<MDL	99	170
Acenaphthylene	1.2		7.7	<MDL	3		0.91	<MDL	66	66
Acenaphthene	5.2		380**		33		3.8		16	57
Fluorene	6.9		380**		40		5.5		23	79
Phenanthrene	30		1200**		160		25		100	480
Anthracene	12		230**		37		9.1		220	1200
2-Methylnaphthalene	2.5	<MDL	170**		7		3.6	<MDL	38	64
Total LPAHs	60.3		2737.7**		292		51.51		370	780
HPAHs (mg/kg TOC)										
Fluoranthene	54		1000*		180		45		160	1200
Pyrene	26		900		100		22		1000	1400
Benzo(a)anthracene	22		320**		57		15		110	270
Chrysene	30		380**		60		20		110	460
Total benzofluoranthenes	40.7		249*		85		30.4		230	450
Benzo(a)pyrene	16		120*		30		10		99	210
Indeno(1,2,3-CD)Pyrene	4.8		50*		1.7		2.7	<MDL	34	88
Dibenzo(a,h)anthracene	2.5	<MDL	19*	<MDL	1.7	<MDL	3.6	<MDL	12	33
Benzo(g,h,i)perylene	4.5		42*		6.3		2.7	<MDL	31	78
Total HPAHs	200.5		3080*		527.7		151.4		960	5300
Other (mg/kg TOC)										
1,2-Dichlorobenzene	0.62	<MDL	7.7**	<MDL	0.67	<MDL	0.91	<MDL	2.3	2.3
1,4-Dichlorobenzene	0.62	<MDL	7.7*	<MDL	0.67	<MDL	0.91	<MDL	3.1	9
1,2,4-Trichlorobenzene	0.62	<MDL	7.7**	<MDL	0.67	<MDL	0.91*	<MDL	0.81	1.8
Hexachlorobenzene	0.62	<MDL	7.7**	<MDL	0.67	<MDL	0.91*	<MDL	0.38	2.3
Diethyl Phthalate	1.9	<MDL	15	<MDL	1.3	<MDL	2.7	<MDL	61	110
Dimethyl Phthalate	0.62	<MDL	3.8	<MDL	0.33	<MDL	0.91	<MDL	53	53
Di-N-Butyl Phthalate	1.9	<MDL	15	<MDL	1.3	<MDL	2.7	<MDL	220	1700
Benzyl Butyl Phthalate	0.62	<MDL	7.7*	<MDL	0.67	<MDL	0.91	<MDL	4.9	64
Bis(2-Ethylhexyl)Phthalate	0.62	<MDL,B	7.7	<MDL,B	0.67	<MDL,B	0.91	<MDL,B	47	78
Di-N-Octyl Phthalate	0.62	<MDL	7.7	<MDL	0.67	<MDL	0.91	<MDL	58	4500
Dibenzofuran	3.9		260**		26*		2.7	<MDL	15	58
Hexachlorobutadiene	1.9	<MDL	15**	<MDL	1.3	<MDL	2.7	<MDL	3.9	6.2
N-Nitrosodiphenylamine	1.9	<MDL	15**	<MDL	1.3	<MDL	2.7	<MDL	11	11
Total PCBs	0.62	<MDL	0.38	<MDL	0.33	<MDL	0.91	<MDL	12	65
Other (µg/kg dry weight)										
Phenol	100	<MDL	1000*	<MDL	100	<MDL	100	<MDL	420	1200
2-Methylphenol	30	<MDL	400*	<MDL	40	<MDL	30	<MDL	63	63
4-Methylphenol	30	<MDL	400	<MDL	40	<MDL	30	<MDL	670	670
2,4-Dimethylphenol	30**	<MDL	400**	<MDL	40**	<MDL	30**	<MDL	29	29
Pentachlorophenol	30	<MDL	400*	<MDL	40	<MDL	30	<MDL	360	690
Benzyl Alcohol	30	<MDL	400**	<MDL	40	<MDL	30	<MDL	57	73
Benzoic Acid	100	<MDL	1000**	<MDL	100	<MDL	100	<MDL	650	650
Metals (mg/kg dry weight)										
Mercury	0.1	<RDL,E	0.65**	E	0.2	<RDL,E	0.06	<RDL,E	0.41	0.59
Arsenic	10	<RDL	10	<RDL	10	<RDL	8	<RDL	57	93
Cadmium	0.4	<RDL,L	2	<RDL,L	0.9	<MDL,L	0.6	<MDL,L	5.1	6.7
Chromium	19		37		19		14		260	270
Copper	32		89		56		21		390	390
Lead	20		170		58		10	<RDL	450	530
Silver	0.7	<RDL	3.5	<RDL	0.9	<RDL	0.6	<MDL	6.1	6.1
Zinc	65		160		82		51		410	960

* - Exceeds SQS

<MDL - Undetected at the method detection limit

<RDL - Detected below reporting detection limits

B - Blank contamination

Note: For further information on data qualifiers see Appendix B.

** - Exceeds CSL

E - Estimate

G - Low standard reference material recovery

L - High standard reference material recovery

TABLE 4-8. Stations VG8, VG10, and VG11, Comparison to Standards

Station	VG8		VG10		VG11		Sediment Management Standards	
Date	May 21, 93		May 21, 93		May 21, 93			
Sample Number	L1145-12		L1145-9		L1145-10			
% Solids	70		51		58			
% Total Organic Carbon	0.99		4.7		5.2			
Organics							SQS Table I	CSL Table III
LPAHs (mg/kg TOC)	Value	Qual	Value	Qual	Value	Qual		
Naphthalene	10		1100**		730**		99	170
Acenaphthylene	7.7		18		13		66	66
Acenaphthene	29*		830**		400**		16	57
Fluorene	58*		740**		370**		23	79
Phenanthrene	290*		1900**		1000**		100	480
Anthracene	60		230*		160		220	1200
2-Methylnaphthalene	8.2		510**		250**		38	64
Total LPAHs	462.9*		5328**		2923**		370	780
HPAHs (mg/kg TOC)								
Fluoranthene	340*		1200**		690*		160	1200
Pyrene	190		870		560		1000	1400
Benzo(a)anthracene	140*		320**		210*		110	270
Chrysene	160*		300*		210*		110	460
Total benzofluoranthenes	224		250*		190		230	450
Benzo(a)pyrene	78		110*		87		99	210
Indeno(1,2,3-Cd)Pyrene	19		40*		27		34	88
Dibenzo(a,h)anthracene	4	<MDL	13*	<MDL	9.6	<MDL	12	33
Benzo(g,h,i)perylene	12		38*		21		31	78
Total HPAHs	1167*		3141*		2004.6*		960	5300
Other (mg/kg TOC)								
1,2-Dichlorobenzene	1	<MDL	4.3**	<MDL	3.8**	<MDL	2.3	2.3
1,4-Dichlorobenzene	1	<MDL	4.3*	<MDL	3.8*	<MDL	3.1	9
1,2,4-Trichlorobenzene	1	<MDL	4.3**	<MDL	3.8**	<MDL	0.81	1.8
Hexachlorobenzene	1	<MDL	4.3**	<MDL	3.8**	<MDL	0.38	2.3
Diethyl Phthalate	3	<MDL	8.5	<MDL	5.8	<MDL	61	110
Dimethyl Phthalate	1	<MDL	2.1	<MDL	1.9	<MDL	53	53
Di-N-Butyl Phthalate	3	<MDL	8.5	<MDL	5.8	<MDL	220	1700
Benzyl Butyl Phthalate	1	<MDL	4.3	<MDL	3.8	<MDL	4.9	64
Bis(2-Ethylhexyl)Phthalate	1	<MDL,B	4.3	<MDL,B	3.8	<MDL,B	47	78
Di-N-Octyl Phthalate	1	<MDL	4.3	<MDL	3.8	<MDL	58	4500
Dibenzofuran	27*		530**		270**		15	58
Hexachlorobutadiene	3	<MDL	8.5**	<MDL	5.8*	<MDL	3.9	6.2
N-Nitrosodiphenylamine	3	<MDL	8.5	<MDL	5.8	<MDL	11	11
Total PCBs	1	<MDL	0.43	<MDL	0.19	<MDL	12	65
Other (µg/kg dry weight)								
Phenol	100	<MDL	1000*	<MDL	1000*	<MDL	420	1200
2-Methylphenol	30	<MDL	400**	<MDL	300**	<MDL	63	63
4-Methylphenol	30	<MDL	400	<MDL	300	<MDL	670	670
2,4-Dimethylphenol	30**	<MDL	400**	<MDL	300**	<MDL	29	29
Pentachlorophenol	30	<MDL	400*	<MDL	300	<MDL	360	690
Benzyl Alcohol	30	<MDL	400**	<MDL	300**	<MDL	57	73
Benzoic Acid	100	<MDL	1000**	<MDL	1000**	<MDL	650	650
Metals (mg/kg dry weight)								
Mercury	0.3	<RDL,E	1.4**	E	1.4**	E	0.41	0.59
Arsenic	10	<RDL	20	<RDL	20	<RDL	57	93
Cadmium	0.9	<RDL,L	4	<RDL,L	3	<RDL,L	5.1	6.7
Chromium	20		51		40		260	270
Copper	34		180		130		390	390
Lead	33		490*		360		450	530
Silver	0.7	<RDL	10**		6.2**		6.1	6.1
Zinc	64		220		190		410	960

* - Exceeds SQS

<MDL - Undetected at the method detection limit

<RDL - Detected below reporting detection limits

B - Blank contamination

Note: For further information on data qualifiers see Appendix B.

** - Exceeds CSL

E - Estimate

G - Low standard reference material recovery

L - High standard reference material recovery

TABLE 4-9. Stations VG1 through VG5, Particle Size Distribution

Station	VG1	VG1 Rep	VG2	VG3	VG4	VG5
Date	May 20, 93	May 20, 93	May 20, 93	May 19, 93	May 19, 93	May 21, 93
Sample Number	L1145-1	L1145-2	L1145-3	L1145-4	L1145-5	L1145-6
% Solids	57	70	57	65	69	57
Phi Size (%)						
Sands and Gravels						
p+0.00	2.6	2	3.4	1.2	3.3	1.2
p+1.00	21	21	15	13	24	15
p+10.0	3.6	2.9	5.1	3.5	2.9	5.5
p+2.00	49	49	37	53	47	41
p+3.00	14	15	19	15	8.3	15
p+4.00	2.3	1.9	4.9	2.7	2	3.9
Total % Sands	92.5	91.8	84.4	88.4	87.5	81.6
Silts and Clays						
p+5.00	0.9	1.4	3.3	3.8	2.1	2.7
p+6.00	1	0.9	2.4	1.1	1.5	3
p+7.00	2.4	2.7	3.1	2.6	3.4	4.4
p+8.00	1.9	2.7	3.6	3.2	3.6	5.5
p+9.00	1.4	0.3	0.6	1.6	0.5	1.9
p-1.00	0.6	0.4	1	0.3	0.7	
p-2.00			0.3			
p-2.25	0.2	0.6	1		0.1	0.5
Total % Silts and Clays	8.4	9	15.3	12.6	11.9	18

TABLE 4-10. Stations VG6 through VG11, Particle Size Distribution

Station	VG6	VG7	VG10	VG11	VG8
Date	May 21, 93	May 21, 93	May 21, 93	May 21, 93	May 21, 93
Sample Number	L1145-7	L1145-8	L1145-9	L1145-10	L1145-12
% Solids	57	72	51	58	70
Phi Size (%)					
Sands and Gravels					
p+0.00	1.1	6.8	3.6	6.3	0.8
p+1.00	11	34	9.3	21	7.4
p+10.0	5.6	2.8	7.2	5.2	3.2
p+2.00	40	39	27	27	57
p+3.00	18	7.1	15	13	17
p+4.00	5.3	1.4	7.1	4.8	2.7
Total % Sands	81	91.1	69.2	77.3	88.1
Silts and Clays					
p+5.00	2.4	1.6	4.7	5.1	4.5
p+6.00	3.2	1	6.4	3.5	1
p+7.00	3.7	0.9	6.8	4.3	2
p+8.00	5.7	2.3	5.8	4.1	2.1
p+9.00	1.6	0.5	1.8	1.3	1.4
p-1.00	0.5	1.9	2	3	0.8
p-2.00	0.4	0.6	0.2	0.5	0.1
p-2.25	1.4	0.3	3.2	1	0.3
Total % Silts and Clays	18.9	9.1	30.9	22.8	12.2

SECTION 5

BENTHIC RECOLONIZATION

In August 1993, the monitoring team conducted a benthic taxonomy study, and in May 1993 a contractor conducted a diver-held video camera survey. This section describes the methods used and reports the results of the study and survey. It also compares the results of the benthic taxonomy study with results from the 1992 baseline taxonomy study, the pre-cap taxonomy study, and the taxonomy study conducted 1 year after capping at the Denny Way site.

METHODS

Benthic Taxonomy

The monitoring plan defined four benthic taxonomy sampling stations situated to provide spatial coverage across the remediation area (Figure 5-1). Two stations are in the ENR (VG3 and VG4), and two stations are in the 3-foot cap area (VG1 and VG2). All four stations are at water depths of 40 to 55 feet, are in areas where the bottom slope is less steep than it is inshore, and are situated near the center of the cap to minimize interference from offsite benthic organisms that could skew the test results.

Benthic taxonomy samples were collected using a 0.1-m² Van Veen grab sampler operated from the *RV Liberty*. Five replicate samples were taken at each station. When a sample was collected and brought onboard, seawater was drained off the sample through a 1-mm mesh screen to capture any benthic organisms that may have been stirred up into the water. Sample thickness was measured to ensure a depth penetration of 10 cm. The contents of the grab sampler were emptied into a plastic tub and then carefully washed into a 5-gallon plastic bucket. Each bucket was labeled separately and stored in the shade until the sample could be screened. Screening consisted of carefully washing the sample through a 1-mm mesh screen with water from a hose to remove fine sediment and debris. Everything that did not wash through the screen was put into a jar and preserved in buffered formalin. The jars were labeled by station and replicate number. Later, the samples were transferred from formalin to alcohol. Sample screening and preservation was performed by Pentec. Taxonomic analysis was conducted by Marine Taxonomic Services.

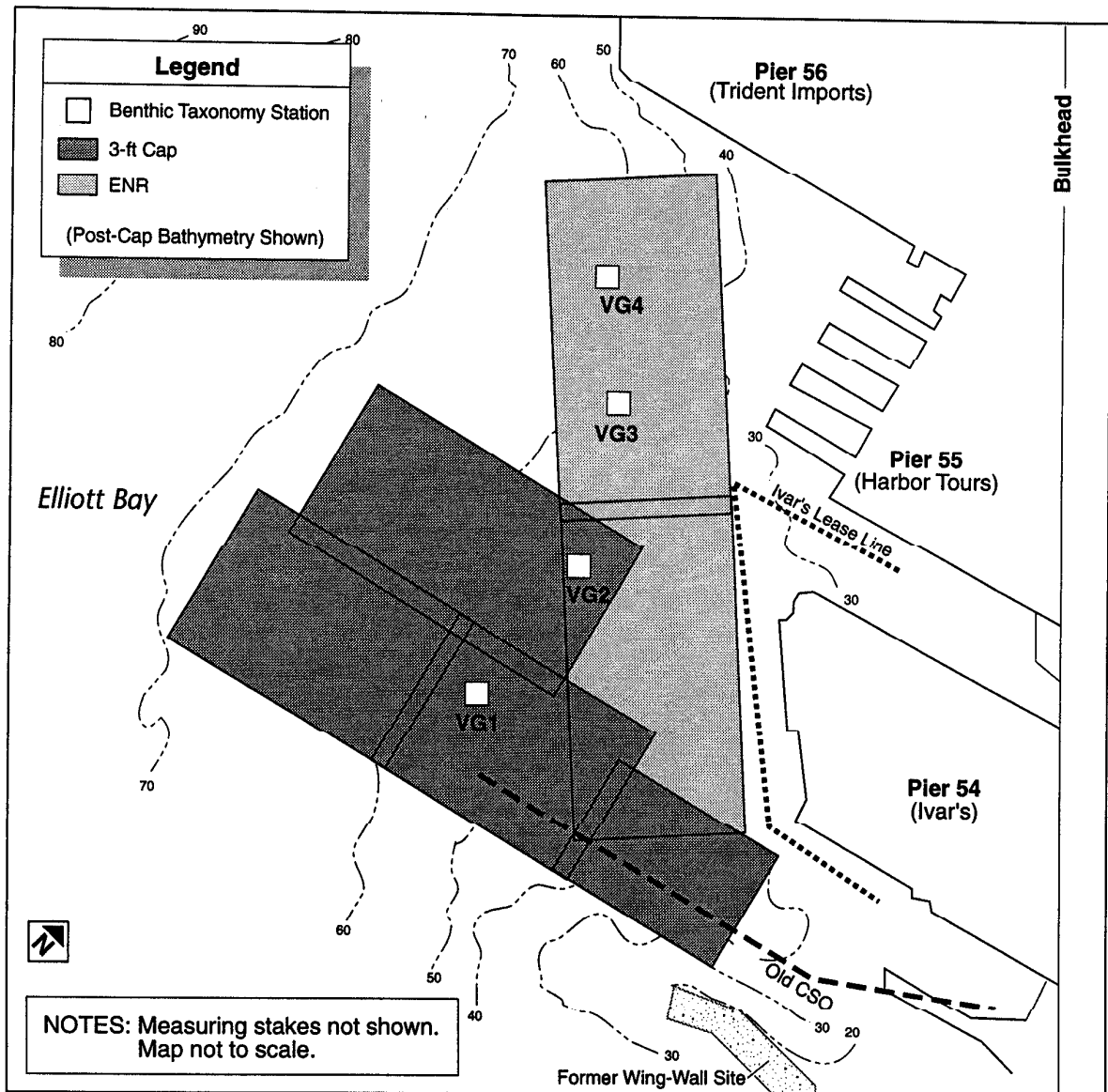


Figure 5-1. Benthic Taxonomy Stations

Video Camera Survey

A contract diver conducted a video camera survey. The diver held a waterproof video camera and swam along four downslope transects on the remediation area while filming (Figure 5-2). The transects were marked by rope

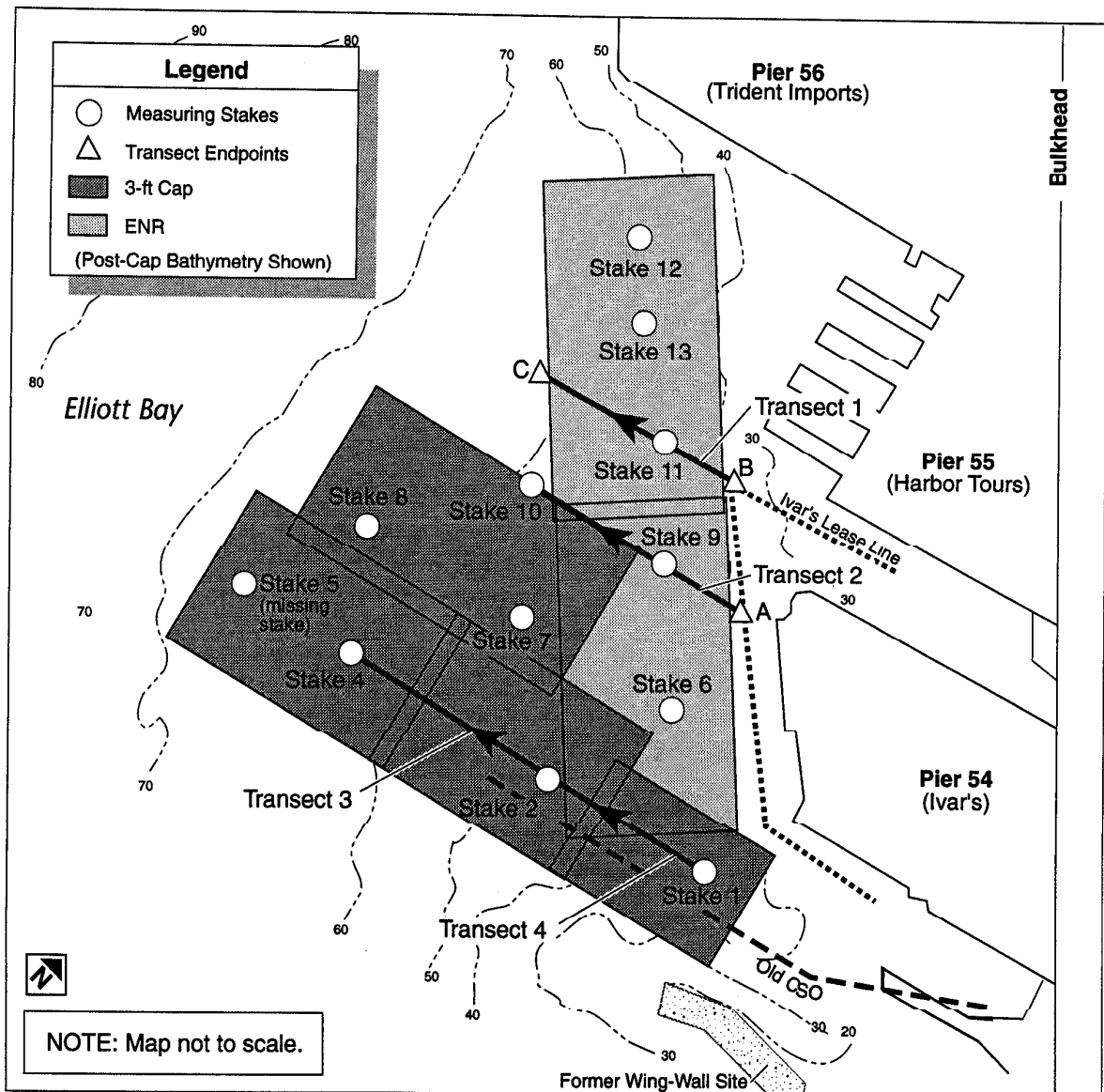


Figure 5-2. Video Camera Survey Transects

strung along the bottom. Anchors, securing the transect ropes, were set in place using a range-azimuth positioning system. The stakes installed for measuring cap thickness and seafloor settlement were used to construct the transects whenever possible.

The *RV Liberty* was anchored near the transect being filmed, and a diver-support boat was tied alongside. The diver was supplied air from onboard the

support boat and was in radio contact with the crew at all times. The video camera was connected to a video monitor onboard the *RV Liberty*, where the crew could view the survey and direct filming. The entire video was approximately 60 minutes long, with 15 minutes for each of the four transects.

The transects were situated to provide spatial coverage over the remediation area. Two transects began outside the remediation area and proceeded onto it to show the change from the native substrate to the cap substrate. Transect 1 began at point B on the inshore edge of the ENR between Pier 54 and Pier 55 and extended offshore to point C at the west edge of the barge tracks. Transect 2 started at point A on the inshore edge of the ENR near the north corner of Pier 54, ran offshore through measuring Stake 9, and ended at Stake 10. Transect 3, located in the middle of the 3-foot cap, ran from Stake 2 to Stake 4. Transect 4 ran from Stake 1 in the southern inshore corner to Stake 2 in the center of the 3-foot cap area.

RESULTS

Benthic Taxonomy

A total of 215 species were counted in the remediation area (Table 5-1). Polychaetes had the greatest number of species (123), while there were 45 mollusk species and 40 crustacean species. The highest number of species was counted at VG3 with 153, while the lowest was at VG1 with 122.

TABLE 5-1. Number of Species					
Taxonomic Group	VG1	VG2	VG3	VG4	Total Species
Polychaetes	77	89	89	77	123
Mollusks	25	25	34	30	45
Crustaceans	17	25	26	27	40
Other	3	5	4	6	7
Total Species	122	144	153	140	215

An average of 923 total individuals per replicate sample were counted in the remediation area (Table 5-2). Polychaetes were the most numerous taxonomic group at all stations, ranging from an average of 908 individuals at VG2 to 445 individuals at VG1. The highest average number of total individuals was found at VG3 with 1,181, and the lowest was found at VG1 with 595.

TABLE 5-2. Average Number of Individuals per Station

Taxonomic Group	Average of 5 Replicates x 0.1 m ²				Totals
	VG1	VG2	VG3	VG4	
Polychaetes	445	908	887	483	681
Mollusks	68	138	192	197	148
Crustaceans	78	70	95	107	88
Other	4	7	7	5	6
Totals	595	1,123	1,181	792	923

The biomass average for the remediation area was 2.87 grams per replicate sample (Table 5-3). Polychaetes showed the highest biomass average at all stations, ranging from 1.35 grams at VG4 to 2.09 grams at VG2. The highest biomass was recorded at Station VG3 with an average of 3.33 grams, and the lowest was at VG1 with 2.14 grams.

TABLE 5-3. Biomass Average per Station

Taxonomic Group	Average of 5 Replicates x 0.1 m ² (Grams)				Totals
	VG1	VG2	VG3	VG4	
Polychaetes	1.5176	2.0866	1.7718	1.3502	1.6816
Mollusks	0.4404	0.8376	1.2334	1.1018	0.9033
Crustaceans	0.1744	0.2454	0.2924	0.299	0.2528
Other	0.0112	0.0748	0.0348	0.0122	0.0333
Totals	2.1436	3.2444	3.3324	2.7632	2.8709

Representative species for each station are presented in Tables 5-4 through 5-7. The top six most abundant benthic species (in descending order) were as follows: *Aphelocheata multifilis*, *Axinopsida serricata*, *Lumbrineris sp. indet.*, *Asabellides lineata*, *Euphilomedes carcharodonta*, and *Prionospio steenstrupi*. *A. multifilis* was the most abundant species found at VG1, VG2, and VG3, and *A. serricata* was most abundant species found at VG4. Ranges for numbers of individuals for the top six most abundant species are as follows:

- *A. multifilis* ranged from an average of 465 individuals at VG2 to 102 individuals at VG4.
- *A. serricata* ranged from an average of 129 individuals at VG3 to 35 at VG1.
- *Lumbrineris* ranged from an average of 159 individuals at VG3 to 49 at VG1.
- *A. lineata* ranged from 85 individuals at VG2 to 47 at VG4.

- *E. carcharodonta* ranged from an average of 80 individuals at VG4 to 37 at VG2.
- *P. steenstrupi* ranged from an average of 65 individuals at VG3 to 34 individuals at VG1.

TABLE 5-4. Representative Species at Station VG1

	Number of Individuals Per 0.1 m ²					
Taxa	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Average
Polychaetes						
<i>Aphelochaeta multifilis</i>	2	2	242	287	219	150
<i>Asabellides lineata</i>	1		72	100	60	58
<i>Capitella capitata</i> complex	1	1	22	14	12	10
<i>Chaetozone setosa</i>			7	21	10	13
<i>Lanassa venusta venusta</i>			11	16	5	11
<i>Lumbrineris</i> sp. Indet.	12	6	60	106	60	49
<i>Polydora brachycephala</i>			32	36	44	37
<i>Prionospio steenstrupi</i>		1	61	54	52	42
<i>Spiochaetopterus costarum</i>	18	31	44	31	32	31
Mollusks						
<i>Axinopsida serricata</i>	4	5	44	70	50	35
<i>Macoma carlottensis</i>			9	17	5	10
Crustaceans						
<i>Euphilomedes carcharodonta</i>	36	29	104	73	60	60

TABLE 5-5. Representative Species at Station VG2

	Number of Individuals Per 0.1 m ²					
Taxa	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Average
Polychaetes						
<i>Aphelochaeta multifilis</i>	516	471	634	385	321	465
<i>Asabellides lineata</i>	150	84	52	55	85	85
<i>Capitella capitata</i> complex	6	31	94	19	14	33
<i>Chaetozone setosa</i>	23	11	10	14	11	14
<i>Lanassa venusta venusta</i>	5	10	3	12	12	8
<i>Lumbrineris</i> sp. Indet.	85	52	131	114	49	86
<i>Polydora brachycephala</i>	18	11	9	14	16	14
<i>Prionospio steenstrupi</i>	31	38	44	52	44	42
<i>Spiochaetopterus costarum</i>	16	6	8	16	15	12
Mollusks						
<i>Axinopsida serricata</i>	120	58	64	146	100	98
<i>Macoma carlottensis</i>	21	12		12	13	15
Crustaceans						
<i>Euphilomedes carcharodonta</i>	37	35	28	50	34	37

TABLE 5-6. Representative Species at Station VG3

	Number of Individuals Per 0.1 m ²					
Taxa	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Average
Polychaetes						
<i>Aphelocheata multifilis</i>	343	516	260	434	338	378
<i>Asabellides lineata</i>	41	77	32	91	37	56
<i>Capitella capitata</i> complex	2	10	2	13	9	7
<i>Chaetozone setosa</i>	11	13	4	3	12	9
<i>Lanassa venusta venusta</i>	5	8	12	23	11	12
<i>Lumbrineris</i> sp. Indet.	146	205	95	189	158	159
<i>Polydora brachycephala</i>	28	23	18	44	61	35
<i>Prionospio steenstrupi</i>	79	74	43	68	63	65
<i>Spiochaetopterus costarum</i>	7	7	8	18	11	10
Mollusks						
<i>Axinopsida serricata</i>	131	125	81	163	144	129
<i>Macoma carlottensis</i>	19	19	6	24	26	19
Crustaceans						
<i>Euphilomedes carcharodonta</i>	64	72	59	60	66	64

TABLE 5-7. Representative Species at Station VG4

	Number of Individuals Per 0.1 m ²					
Taxa	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Average
Polychaetes						
<i>Aphelochaeta multifilis</i>	61	59	224	98	68	102
<i>Asabellides lineata</i>	48	35	86	56	12	47
<i>Capitella capitata</i> complex	3	3	5	6	1	4
<i>Chaetozone setosa</i>	5	10	19	3		9
<i>Lanassa venusta venusta</i>	20	18	12	10		15
<i>Lumbrineris</i> sp. Indet.	60	83	158	89	69	92
<i>Polydora brachycephala</i>	25	48	18	22	4	23
<i>Prionospio steenstrupi</i>	55	49	77	52	6	48
<i>Spiochaetopterus costarum</i>	13	10	25	24	4	15
Mollusks						
<i>Axinopsida serricata</i>	134	171	126	110	96	127
<i>Macoma carlottensis</i>	20	26	13	14	8	16
Crustaceans						
<i>Euphilomedes carcharodonta</i>	86	73	92	79	72	80

Video Camera Survey

The diver swam off the transect line during the taping of Transect 4, between Stakes 2 and 1, and was unable to find it again because of poor visibility. Therefore, the area closest to shore at the southern end of the cap was not filmed.

The video showed many burrows, tubes, and other evidence of benthic life in the remediation area. Many flounder, anemones, nudibranchs, starfish, and

several types of crabs were filmed. Also, many small plants were beginning to root into the sand.

In comparison with the surrounding areas, the cap was relatively clear of debris. The surface was flat with occasional piles of small wood debris that was probably dredged along with the capping sand from the Duwamish River. Images taken inshore of the cap edge near the piers showed much more trash, old piles, and other debris littering the bottom. More marine vegetation was growing along the edges of the cap than in the center, possibly because there was more debris where vegetation can anchor.

No ripples or other evidence of erosion were filmed. The cap was covered by a tan-colored fine-grain layer of silt. This silt layer, which was easily disturbed by the diver, appeared to have become thicker since 1992. It is apparent that if there were marine currents strong enough to erode capping sand, they would have washed away this silt layer first.

DISCUSSION OF BENTHIC TAXONOMY

Spatial Distribution

Comparing the number of species, the average number of individuals, and the biomass at each station showed that VG3 was the highest in all categories and that VG1 was the lowest. VG1 was located the farthest south of all the benthic stations and was on the 3-foot cap, while VG3 was farther north and was on the ENR. Productivity differences between the 3-foot cap and the ENR, however, were not apparent. VG2, which was on the 3-foot cap, was similar to VG3 in abundance, number of species, and biomass, while VG4, located on the ENR, was lower than the averages for the entire remediation area. Spatially, the least productive stations were at the north and south ends of the remediation area, and the most productive were in the middle of the remediation area.

VG3 had 9 percent greater number of species, 5 percent higher average number of individuals, and a 4 percent higher average biomass than the averages for the entire remediation area. VG1 had 13 percent fewer species, 36 percent lower average number of individuals, and a 25 percent lower average biomass than the averages for the entire remediation area.

It is not clear if the lower numbers of individuals, species, and biomass at VG1 are associated with its proximity to the contamination found on the

southern edge of the remediation area. It also could not be determined what effect the contamination in the rest of the remediation area had on the benthic communities. None of the benthic stations were located where the greatest recontamination occurred. Given the increase in the numbers of species and the presence of species that are known to be sensitive to organic pollution, such as *Asabellides lineata*, the benthic community did not show short-term effects from the contamination. However, it is possible that long-term effects will be manifested by decreasing productivity approaching the area of greatest contamination.

Comparison to the Pre-Cap and 1992 Baseline Studies

Comparisons of benthic taxonomy parameters for pre-cap baseline and 1993 studies appear in Tables 5-8 through 5-10 and Figure 5-3. Discussions of the comparisons follow.

TABLE 5-8. Average Numbers of Individuals Comparison

Taxa	Pre Cap	1992 Baseline	1993
Polychaetes	315	177	681
Mollusks	337	37	148
Crustaceans	120	27	88
Other	7	17	6
Totals	781	258	923

TABLE 5-9. Numbers of Species Comparison

Taxa	Pre Cap	1992 Baseline	1993
Polychaetes	109	80	123
Mollusks	53	26	45
Crustaceans	34	24	40
Other	7	9	7
Totals	203	139	215

TABLE 5-10. Biomass Comparison

Taxa	Pre Cap	1992 Baseline	1993
Polychaetes	6.28	1.63	1.68
Mollusks	0.58	0.08	0.9
Crustaceans	11.52	0.11	0.25
Other	0.35	0.2	0.033
Totals	18.73	2.02	2.87

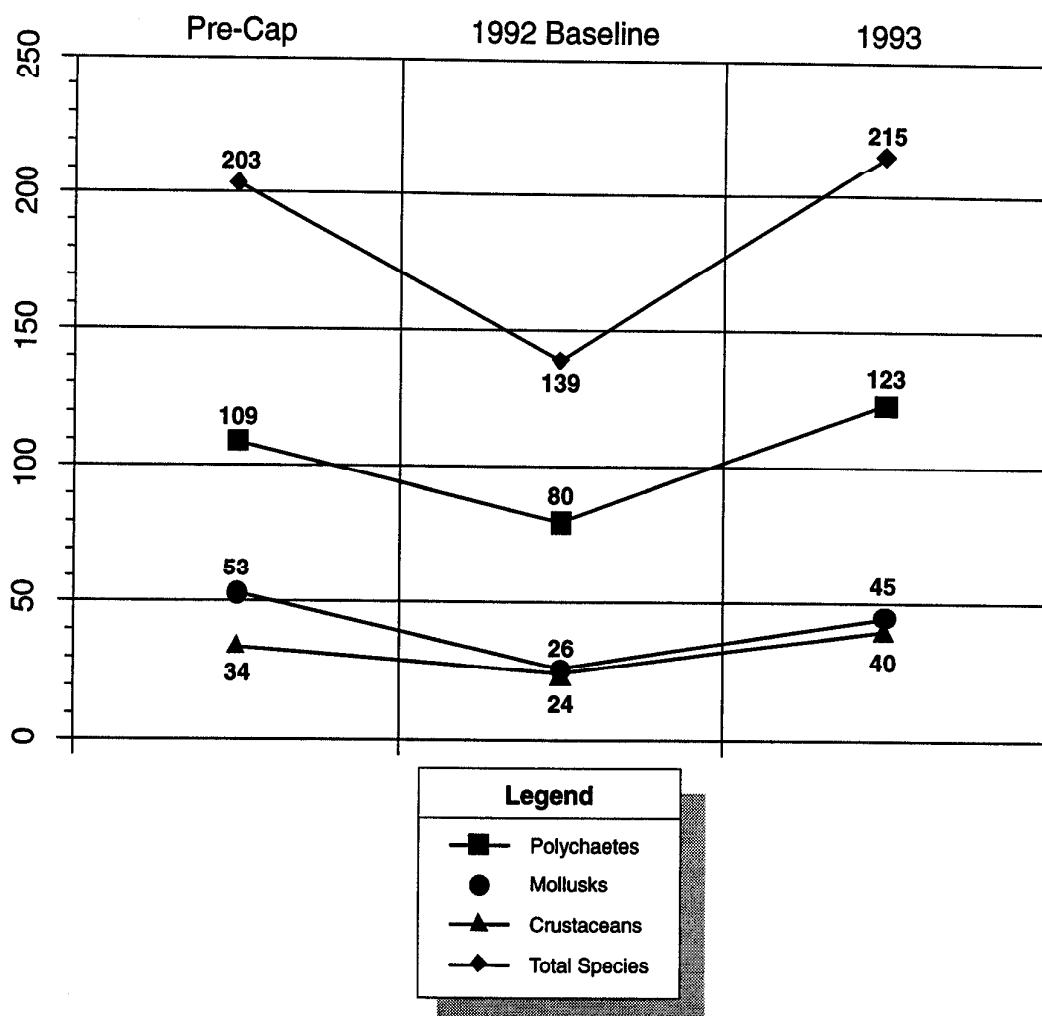


Figure 5-3. Comparison of Numbers of Species

Comparison to 1992 Baseline Study. A comparison of the baseline 1992 benthic taxonomy study to the 1993 benthic taxonomy study showed that the average number of individuals in each 0.1 m² replicate sample at all stations increased in 1993 by approximately 400 percent, the number of species increased by 55 percent, and the biomass increased by 30 percent.

As in 1993, VG1 had the lowest species, number of individuals, and biomass in 1992. However, the differences between VG1 and the averages for the entire remediation area increased during the year. VG1 had 10 percent fewer species in 1992 and 13 percent fewer in 1993, a 13 percent lower average number of

individuals in 1992 compared to a 25 percent lower average in 1993, and 12 percent less biomass in 1992 and 25 percent less in 1993 than the remediation average.

The top six most numerous species in the 1992 baseline study were *Pectinaria californiensis*, *Spirochaetopterus costarum*, *Prionospio steenstrupi*, *Macoma* sp. juv., *Nephtys cornuta*, and *Euphilomedes carcharodonta*. *E. carcharodonta*, *S. costarum*, *P. steenstrupi*, and *Macoma* continued to be among the most abundant species in 1993.

Among pectinarids, *P. californiensis* declined from an average of 26 individuals per replicate sample at all stations in 1992 to an average of 2 in 1993, while *P. granulata* increased from an average of 3 individuals in 1992 to an average of 10 individuals in 1993. Pectinarids are normally associated with a stable environment and an established benthic community. The relatively high numbers of *P. californiensis* in the 1992 baseline study was unusual considering the short time period between capping and monitoring. Their initial high numbers could have been because of a local biological bloom shortly before the baseline samples were taken.

A number of juvenile *Macoma* (bivalves) found on the cap in 1992 appear to have developed into adults. In 1992, all species of *Macoma* combined averaged less than 1 adult per replicate sample at all stations, while in 1993 *M. carlottensis* averaged 15 adults per replicate sample for all stations. Other adult *Macoma* species also showed increases.

In 1992, seven *Aphelocheata multifilis* individuals were counted in all replicate samples at all stations. In 1993, they averaged 274 individuals per replicate sample at all stations, becoming the most abundant species on the cap. *Axinopsida serricata* increased from an average of one individual per replicate sample for all stations in 1992 to 97 individuals in 1993. *Asabellides lineata* was undetected in 1992 but averaged 61 individuals per replicate sample for all stations in 1993.

Comparison to the Pre-Cap Study. A comparison of the pre-cap benthic taxonomy study, which was conducted just before the cap was placed in 1992, to the 1993 benthic taxonomy study showed that the average number of individuals in each 0.1 m² replicate sample at all stations and the total number of species was higher in the 1993 study. Biomass, however, was higher in the

pre-cap study by a factor of six. Greater numbers of individuals and lower biomass in 1993 indicate that, as expected 1 year after capping, the individual organisms are smaller.

Axinopsida serricata, *Lumbrineris* sp. Indet., *Euphilomedes carcharodonta*, and *Prionospio steenstrupi* were among the top six most abundant in both the pre-cap and the 1993 studies. At the same time, however, *Aphelochaeta multifilis* went from very few individuals in the pre-cap study to the most abundant species in the 1993 study. Also, the ampharetid *Asabellides lineata* went from being undetected in the pre-cap study to the fourth most abundant species in the 1993 study. Ampharetids have shown a strong negative correlation to sediment contamination in past studies and have been classed a "sensitive or intolerant taxa" because they tend to occur in more pristine sites (Metro, 1987). *Heteromastus filobranthus*, a capitellid, went from being in the top four most abundant species in the pre-cap study to very few individuals in the 1993 study. Capitellid polychaetes have been used as indicators of organically polluted sediments (Pearson and Rosenberg, 1978).

Comparison to the Denny Way Cap.

Taxonomic comparisons between the Pier 53 cap and the Denny Way cap 1 year after cap placement showed that many species were present in similar proportions at both sites. The total number of species and the average number of individuals per replicate sample, however, were significantly higher at Pier 53, while biomass was significantly higher at Denny Way.

Samples were taken from the Denny Way cap at two benthic taxonomy stations, J and M. Collection methods, screening, and species identification were the same as for the Pier 53 samples and were conducted by the same contractors. The Pier 53 and Denny Way taxonomy studies were both conducted in August because it was anticipated that biomass would be highest at this time.

Aphelochaeta multifilis, *Lumbrineris* sp. indet., and *Euphilomedes carcharodonta* were among the six most abundant species at both caps. Other species found in abundance at both caps include *Prionospio steenstrupi*, *Axinopsida serricata*, and *Spiochaetopterus costarum*. *Capitella capitata*, a known indicator of organic enrichment, was found in greater numbers at Denny Way than at Pier 53. *Asabellides lineata*, known for being sensitive to sediment contamination, was found in abundance at Pier 53 but was not detected at Denny Way.

The total number of species and the number of species for all taxonomic groups was higher at Pier 53, with total of 215 species compared to 159 at Denny Way. The total average number of individuals per replicate sample was higher at Pier 53, with 923 compared to 572 at Denny Way. Although the number of individuals was higher at Pier 53, biomass was almost 2 times greater at Denny Way. The biomass average at Denny Way was 5.39 grams per replicate sample compared to 2.87 grams per replicate sample at Pier 53.

Fewer species and higher biomass probably means that the Denny Way CSO is having an effect on the nearby benthic community. However, a benthic community experiencing organic enrichment usually shows higher numbers of individuals. Further study of the Denny Way benthic community and a reference sample will be needed to determine what effect the Denny Way CSO is having on the surrounding benthic community.

SECTION 6

CONCLUSIONS AND OUTCOMES

Results of monitoring at Pier 53 in 1993, almost 1 1/2 years after placing the cap and ENR, show that the 3-foot cap and ENR have been successful in achieving their primary purpose of isolating contaminated bottom sediments from the marine environment. However, the surface of the area has been significantly recontaminated since the previous monitoring a year earlier. The recontamination is apparently the result of demolition of a wing wall at the adjacent ferry terminal.

CONCLUSIONS

Specific conclusions from the 1993 monitoring of the Pier 53 remediation area are as follows:

- The 3-foot cap and ENR are stable. They are not eroding or settling into the native bottom muds. Some indications of disturbance and additional thickness in the southern edge of the area were most likely caused by demolition of the ferry terminal wing wall.
- Contaminants are not migrating from the underlying sediments up into the 3-foot cap and ENR. Samples showed a dramatic contrast between the high concentrations in the underlying sediments and the low or undetected concentrations in the cap and ENR. Results of core samples of the underlying sediments do indicate more contaminants in the 1993 under-cap samples than in the 1992 samples. This may be due to core sampling procedures.
- The entire surface of the 3-foot cap and ENR have been recontaminated, as indicated by chemical analyses of 2-cm deep surface samples. These samples showed that the southeast corner of the remediation area exceeds state sediment standards. Chemical concentrations and visual observations show a strong correlation to the demolition of the ferry terminal wing wall. Cleanup of the cap and the ferry terminal area is being discussed by WSDOT, Ecology, and the Panel.

- Despite the recontamination, benthic taxonomy counts indicate that the number of individuals, number of species, and biomass are greater in 1993 than in 1992. Taxonomy counts showed no productivity differences between the 3-foot cap and the ENR. The number of species and individuals was higher in 1993 than before the cap and ENR were placed, although biomass was lower. These increases show that improved sediment quality has had a positive effect on the benthic community. It is not clear if reduced numbers of individuals, species, and biomass at one station on the 3-foot cap were associated with its proximity to the ferry terminal wing wall. No benthic taxonomy stations were located near the highest levels of contamination in the remediation area, and, consequently, biological effects of the contamination could not be determined.

OUTCOMES OF 1993 MONITORING

Since the Pier 53 cap was placed in 1992, the project has affected construction and remediation activities along the downtown Seattle waterfront. Because of successful capping projects at Pier 53 and at the Denny Way CSO, the Port of Seattle constructed a sediment cap at Piers 64-66. Expansion of the downtown passenger-only ferry terminal was delayed because monitoring at Pier 53 showed that WSDOT construction activities may have resuspended and redistributed contaminated sediments. WSDOT has hired a consultant to study the contamination in the bottom sediments surrounding the ferry terminal. In November 1993, the Panel commissioned a waterfront recontamination study to determine the effect resuspension and redistribution of contaminated bottom sediments may have on future sediment remediation projects.

New Cap at Piers 64-66

In March 1994, contractors for the Port of Seattle removed many creosote-covered pier piles that were lying on the bottom and placed approximately 11,000 cubic yards of clean capping sand in the area just offshore of Piers 64, 65, and 66. The cleanup of the old piles and the placement of the sediment cap were part of the first phase in the construction of a short-stay marina and the reconstruction of Pier 66. The sediment cap covers 3.6 acres of contaminated bottom sediments and is 1 to 1.5 feet thick. An additional 1,500 cubic yards of larger cobbles and gravel was selectively placed on top of the cap to provide attachment locations for macroalgae.

A sediment cap was chosen to remediate the site in part because sediment capping projects at Pier 53 and at the Denny Way CSO have shown that sediment capping is successful at isolating contaminated bottom sediments from the marine environment.

Pile Removal Workshop

Since the recontamination of the Pier 53 cap, the effect of in-water construction activities has become a concern along the Seattle waterfront and in other urban environments. As a result, state and federal regulatory agencies, pile removal contractors, property owners, and other interested parties met at a workshop to discuss pile removal in the marine environment. Workshop participants agreed that the common practice of digging into the bottom with a clamshell bucket to locate and remove broken piles is a problem because it stirs up a significant amount of sediment and redistributes contaminants. Participants gained a new awareness of the problem of resuspending contaminated sediments in the marine environment. Additional meetings are being held to develop guidance for minimizing resuspension and redistribution of contaminated sediment during pile removal and pier renovation.

WSDOT Activities

In response to the contamination found at the Pier 53 site, WSDOT temporarily halted construction of the downtown Seattle passenger-only ferry terminal and hired a consultant to collect sediment samples in the area surrounding the former auxiliary ferry dock and to the south of the ferry terminal. The samples helped determine the aerial extent and the depth of the contamination.

The sampling included 10-cm deep grab samples and up to 6-m deep core samples. Sampling included the resampling of four on-cap and two off-cap surface stations from the Pier 53 monitoring program. In general, the concentrations in the 10-cm deep grab samples were lower than in the 2-cm deep grab samples collected in 1993 during the Pier 53 monitoring program. Core samples revealed high concentrations of PAHs 6 meters deep in some areas. Discussions between the Panel and WSDOT concerning the contamination in the ferry terminal area have focused on conducting coordinated cleanup efforts of the Seattle waterfront.

Elliott Bay Waterfront Recontamination Study

Because of the potential for recontamination of cleanup projects along the Seattle waterfront, the Panel funded a waterfront recontamination study to

determine the feasibility of undertaking sediment remediation projects in the waterfront area by 1997. The study is being managed by Ecology. A sampling plan was developed in 1993 (Ecology 1993), and a year of field work was conducted from October 1993 to October 1994.

Results indicate that a cleanup along the waterfront would be feasible but that large areas of the waterfront should be cleaned up at one time. Because sediment contamination is ubiquitous along the waterfront and boat traffic and storm-wave action can resuspend and redistribute bottom sediments, smaller cleanup areas run the risk of becoming recontaminated by surrounding unremediated areas. The study recommended two large cleanup areas. The first is a southern area that extends from Pier 46 north to the south side of the ferry terminal. The second is a northern area that extends from the north side of the ferry terminal north to Pier 59. The study also found that capping should be a feasible alternative but that a cap in the southern area should be monitored to determine if armoring may be needed. Dredging could also be considered in areas where navigation depth needs to be maintained (Ecology and Ana Nova Consultants, Inc., 1995).

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APPENDIX A

MONITORING PLAN FOR PIER 53

**MONITORING PLAN FOR PIER 53;
SEDIMENT CAPPING SITE AND
ENHANCED NATURAL RECOVERY AREA
SEPTEMBER 1992**

**CITY OF SEATTLE
DRAINAGE AND WASTEWATER UTILITY
710 SECOND AVENUE
SEATTLE 98104-1598**

**MUNICIPALITY OF METROPOLITAN SEATTLE
821 SECOND AVENUE
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**MONITORING PLAN FOR PIER 53;
SEDIMENT CAPPING SITE AND
ENHANCED NATURAL RECOVERY AREA
SEPTEMBER 1992**

Project Description-Site Selection and Remediation Methods

This project site was selected as the City of Seattle's first sediment remediation site in Elliott Bay. Site selection was based on several factors including degree of contamination, completion of source control efforts, and simplification of property ownership issues (refer to unpublished draft report "Metro Toxic Sediment Remediation Project", Parametrix, August 1991). An interagency advisory panel, including EPA and Ecology was consulted to determine the criteria for site selection. One suggestion of the panel was that initial remediation efforts be confined to parcels of public ownership, in order to minimize legal disputes regarding access and responsibility. The Pier 53 site is on property owned by the Washington State Department of Natural Resources and is at the location of a former deep water sewer outfall. The deep water outfall has been abandoned. There is presently a combined sewer overflow adjacent to the site which has been controlled to a maximum of one event per year. There is also a stormwater outfall at the same location, which is at the end of Madison Street.

Potentially contaminated areas exist adjacent to the site under piers 53, 54, and 55. These areas are not accessible for capping by the proposed placement method and were not included in the project scope. During the course of project monitoring, sediment samples will be taken from adjacent properties and provided to Ecology for consideration of future remediation action. If any recontamination of the site occurs, these adjacent properties will be evaluated as potential material sources. At this time the migration effects of contaminated sediments from adjacent sites onto the clean cap material are unknown; the data collected from this site will be valuable for planning and coordinating future remediation projects along the central waterfront.

The project involves two different approaches to sediment remediation. The primary approach is to place a three foot cap of clean dredged material to isolate the contaminated sediments. This cap will be placed on the deeper portions of the project site, covering approximately 2.9 acres. The second approach involves the experimental placement of a one foot layer of clean dredged material on the near shore portion of the site, covering an area of 1.6 acres. This is referred to as enhanced natural recovery. This experimental remediation action was required by Washington State DNR as a condition of project approval in order to minimize the potential future navigational impacts of capping and also to provide some experimental data on the feasibility of using a thinner layer of material to accomplish remediation in shallower areas.

The intent of the three foot cap is to isolate the underlying contaminated sediments and to provide a clean substrate for bottom dwelling and bottom feeding organisms. A three foot

cap depth is generally considered to be sufficient to prevent burrowing organisms from breaching the lower cap boundary and entering the underlying contaminated sediments. This method has been used before as a remediation technique in both Commencement Bay and Elliott Bay. The Elliott Bay project is at the Denny Way site, which was capped by METRO in 1990. The proposed project would use clean dredged materials from the turning basin in the Duwamish River, which was also the material source for the Denny Way site. Sediment will be provided and placed by the US Army Corps of Engineers using split hull scows similar to those used at the Denny Way site.

The intent of the one foot thick enhanced natural recovery area is to attempt a recovery method that would be applicable to shallow urban areas where a thicker cap may affect navigational uses or would be logistically difficult to place, such as under piers or adjacent to bulkheads. There are three potential benefits to this approach. A one foot sediment placement would minimize the loss of navigational depth. It may also allow the larger organisms existing on the site to migrate through the sediment and to recolonize the new material. Lastly, the placement of small amounts of clean material may help accelerate the natural degradation of organic chemicals by the biological community.

Objectives

Environmental monitoring for the project involves both short term activities needed to facilitate material placement and to establish baseline information, plus longer term activities needed to document the functional success of the remediation efforts. The strategy for long term monitoring is to do a baseline monitoring within three months of placement, and to repeat monitoring both one, two, and ten years after placement. One other year of monitoring will be added, the timing of which will be decided based on the results of the first two years of monitoring.

There are seven main objectives associated with the monitoring program as listed below. A summary of the sampling activities and schedule are provided in Table 1 and sampling stations are shown in Figure 1.

- | | |
|-------------|--|
| OBJECTIVE 1 | Provide baseline taxonomic data. |
| OBJECTIVE 2 | Guide and document the sediment placement, thickness, and long term stability. |
| OBJECTIVE 3 | Document how well the three foot cap and the enhanced natural recovery area function to isolate contaminated sediments from migrating upwards into the cap, and to document the extent of that contamination if it occurs. |
| OBJECTIVE 4 | Identify whether chemicals accumulate on the remediation site such that they indicate migration of materials from off-site. |

- OBJECTIVE 5 Determine the amount and type of benthic recolonization that occurs on the project site and determine whether there are differences in the character and rate of recolonization between the three foot cap and the one foot thick enhanced natural recovery area.
- OBJECTIVE 6 Review and evaluate the monitoring data with the regulatory agencies to determine (1) if the three foot cap is functioning as expected to isolate contaminated sediments; (2) if a one foot layer of sediment will function as expected such that biological mixing occurs to enhance natural recovery; (3) whether further actions are warranted for either the capping site or the enhanced natural recovery area.
- OBJECTIVE 7 To provide data that may inform and assist the NOAA panel and other agency teams in developing future clean up plans for Elliott Bay.

Cap Placement and Thickness

Bottom stakes will be used to document the placement and thickness of capping" sediments. These will be set by divers inside the area of intended remediation in order to verify the thickness of the placed materials. Stake locations are shown on Figure 1. Initial readings to verify the depth of the new material will be made during the initial monitoring period. An independent check on the thickness of the "capping" materials will also be obtained when sediment cores are collected and processed during the post-placement monitoring discussed in the next section.

A sediment-profile camera survey of the project area and the adjacent seafloor will be conducted in conjunction with the benthic infaunal sampling. One objective of this survey will be to map the areal distribution of capping material at the site. Surface (0-20 cm) sediment grain-size and microstratigraphic layering will be determined from the images and mapped. The sediment-profile surveys, consisting of approximately 100 sampling locations, will be conducted several times throughout the monitoring program, including years 1 and 2. These surveys will allow the distribution of capping material to be mapped over time. These data will supplement the stake observations and core data, and provide a measure of cap dispersal and erosion.

Two follow-up diver surveys of "cap" thickness will be conducted within the four years as summarized in Table 1. These will be conducted at approximately 27 and 51 months after the material is placed to see if there are any obvious differences in the thickness of that material. An analysis of each years data will be included in a report and discussed during a report review meeting and during the four year review. Decisions about when to conduct further bathymetricor diver surveys beyond 51 months will be made in conjunction with Ecology, DNR, EPA, and the Corps of Engineers during the four year review process.

Isolation of Contaminants

Sediment cores will be used to determine if there is any vertical migration of chemicals up into the clean "cap" material. A total of five coring stations will be established as shown in Figure 1. Three coring stations are located in the area of the three foot cap, and two coring stations are located in the area of the one foot experimental enhanced recovery area. These coring stations provide spatial coverage across the project site and are intentionally located a minimum of 50 feet away from other sampling stations so that any potential release of contaminated sediment from the cores will not affect other surface sediment sampling stations.

One core will be collected from each of the five stations. Each core will extend completely through the clean remediation material and into the underlying contaminated sediments about one foot, as shown in Figure 3. Six-inch long sections of the cores will be retained as samples for chemical analysis. Where the three-foot cap is placed, one (1) 6-inch section will be taken below the interface and four (4) of the 6-inch core sections will be taken from above the interface, for a total of five sections. Where the one foot thick material is placed, one (1) 6-inch section will be taken below the interface but only one (1) or two (2) 6-inch sections will be taken from above the interface, depending on the actual material depth achieved by placement. Because mixing can occur around the interface due to the physical process of sediment placement, it is important to leave a space of at least one inch above the interface before taking the first sample. The exact distance will be determined after inspecting the interface of each baseline core, but will remain the same for future cores.

Sediment cores required to establish baseline data will be collected as soon as practical within three months after cap placement. All sections of each baseline core will be analyzed for metal and organic priority pollutants including as a minimum, those required by Washington State Sediment Standards (ref: WAC-173-204). Future core samples will be collected adjacent to the baseline stations to allow comparison of data. All sample sections will be collected for each core taken after the baseline cores, but initially only the first section above the interface will be analyzed for those chemicals found in the underlying contaminated sediments, to determine whether any chemical migration is evident. If chemical migration appears evident, sections further up the core will then be analyzed to determine how far chemical migration extends into the clean "cap" material. Decisions about whether to analyze additional sections will be made within the storage times established under the Puget Sound Protocols.

Additionally, if chemical contamination appears in the enhanced natural recovery area (one foot thick sediments) two avenues of contamination will be considered. If the contamination occurs at the top of the cap material, biological mixing from underlying sediment or deposition of new contamination will be suspected. If the contamination occurs in the bottom only, contamination from migration will be suspected.

Evaluation of vertical migration in the bottom of the "capping" materials will be limited to only chemicals that were present in the underlying sediments. Data will be normalized to dry weight to allow comparisons. Vertical migration from the "cap" downward will be evaluated if there is evidence of significant chemical accumulation on the project site based

on surface sediment samples. Also, a direct measure of cap thickness will be made and compared to the thickness indicated by the bottom depth surveys.

Initial core sampling will be done within three months of "cap" placement. Subsequent sampling will be done one year, four years, and ten years after the initial sampling. An analysis of each years data will be included in a monitoring report and the results discussed during a report review meeting and during the four year review. Decisions regarding the possibility of an additional core sampling between the four year and ten year sampling events will be made in conjunction with Ecology, DNR, EPA, and the Corps during the four year review process scheduled for 1996.

Surface Contamination of Project Site and Adjacent Property

To provide information requested by Ecology and EPA, surface contamination of adjacent property will be determined by collecting and analyzing samples from six stations in 1992 as shown on Figure 1 and 2. Four of these sample sites are located east of the project under the piers; samples from these sites will be collected either by diver or by small grab. Two of the stations are located south of the project site and will be collected with a Van Veen grab sampler. A stainless steel "cookie cutter" will be used to collect the top two centimeters of sediment from three replicate samples per station. These sub-samples will be composited, and then analyzed for priority pollutants, metal and organic including all the routine Ecology sediment chemical parameters. Data for all stations will be normalized to dry weight for comparison between stations and years. Data from these six stations will be provided to Ecology for comparison to other areas along the Seattle waterfront.

Accumulation of surface sediment contamination on the project site will be evaluated by collecting and analyzing samples from seven stations as shown in Figure 1. Samples will be collected with a Van Veen grab sampler. A stainless steel "cookie cutter" will be used to collect the top two centimeters of sediment from three replicate samples per station. These sub-samples will be composited, and then analyzed for priority pollutants, metal and organic, including all the routine Ecology sediment quality chemicals. Data for all stations will also be carbon normalized for comparison to the state sediment standards.

Chemistry data will be compared to the previously collected data (baseline and 15 month) to determine whether a change has occurred. If significant accumulation has occurred, there will be an assessment of the chemistry data from adjacent sites (as noted above) to evaluate whether they are a contributing source.

Initial surface sediment samples will be taken three months after placement. Subsequent samples will be taken one year, four years, and ten years after initial sampling. An analysis of each years data will be included in the monitoring report and discussed during a report review meeting and during the four year review. Decisions about the need, the frequency, and the extent of surface sediment sampling for the period between the four year and ten year samples will be made in conjunction with Ecology, DNR, EPA, and Corps of Engineers during the four year review process in 1996.

Benthic Recolonization

Benthic conditions immediately prior to capping will be documented by collecting and analyzing sediment samples from two stations in the enhanced natural recovery area. A Van Veen sampler will be used to collect five replicates per station and samples will be processed according to Puget Sound protocols. Benthic taxonomy samples will be screened through a standard 1.0 mm mesh and all organisms identified to the lowest practical taxonomic level (preferably to species).

To evaluate recolonization of the project site, taxonomic data will be collected from two stations on the three foot cap and two stations on the enhanced natural recovery area as shown on Figure 1. This should provide a reasonable representation of the type of recolonization that occurs over the entire project site. Also, this allows a comparison between recolonization on the three foot cap and the one foot thick enhanced natural recovery area. The first post-placement sampling will occur in summer of 1992. A Van Veen sampler will be used to collect five replicates per station and samples will be processed according to Puget Sound protocols. Benthic taxonomy samples will be screened through a standard 1.0 mm mesh and all organisms identified to the lowest practical taxonomic level (preferably to species). Table 1 shows the schedule for benthic taxonomy sampling which will yield initial samples at about 5 months, after cap placement. Subsequent samples will be taken one year, four years and ten years after initial sampling. Decisions about taxonomy sampling between the four year and ten year sampling event will be determined in conjunction with Ecology, DNR, EPA, and the Corps of Engineers. Data will be included in a monitoring report and then discussed during a report review meeting and during the four year review. This recolonization analysis will involve comparing each years data to the previous data and at the end of four years to an appropriate reference station.

As described above, a sediment-profile survey of the site will be conducted to map the near-surface distribution of capping material at and adjacent to the site. During the first year survey, approximately 100 images will be collected and given a "quick look" analysis to determine the grain size, Redox Potential Discontinuity depth, depth of penetration, and infaunal successional stage. During subsequent years surveys, up to 24 images will be selected for a more detailed analysis of geochemical and biological parameters with a technique known as REMOTS analysis (Rhoads and Germano, 1986; 1982). These 24 images will be selected to include the three foot capping area, the natural recovery area, and the areas adjacent to the project site. The REMOTS image analysis will include the mapping of "apparent" Redox Potential Discontinuity (RPD) depths and infaunal successional stages. These data will be used, in conjunction with the benthic infaunal data, to document the pattern(s) of benthic recolonization and biogenic sediment reworking across the study area. Sediment-profile surveys will be conducted at the same intervals as the benthic taxonomy sampling.

Review and Evaluation Process

A review process will be conducted on a regular basis to evaluate the monitoring data and determine if the cap is functioning as expected. To help facilitate this review, a monitoring

report will be prepared that presents and analyzes the data. The monitoring report will be produced once each year that new monitoring data is obtained. Table 2 provides an outline of the topics to be addressed in the monitoring report.

Each monitoring report will be distributed to DNR, Ecology, EPA, the Corps of Engineers, and other interested groups, including the NOAA panel that will direct the City of Seattle/Metro settlement action. A meeting will be held to discuss and evaluate the report and conclusions for each year that a report is issued. A major monitoring review will be conducted after four years and will include discussions about monitoring needs beyond four years. These discussions will consider whether the cap is functioning as expected and what contingency actions might be warranted if the cap is not functioning as expected, including whether resulting conditions at the cap surface warrant further action.

Table I. Summary Schedule of Monitoring Activities for Pier 53 Capping

DESCRIPTION OF ACTIVITY	Construction Phase	Ten Year Plan Post Cap Monitoring										
		1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002*
Set Bottom Stakes												
Bottom stake measurements by diver	X	X										
	X	May	August		August							August
Sediment cores for chemistry, 5 stations total												
3 stations on 3' cap (5 depth segments)		May	August			August						August
2 stations on enhanced natural recovery area (2 or 3 depth segments)		May	August			August						August
Surface grabs for chemistry-- adjacent to site, 6 stations (3 stations top 2 CM + top 6 CM) (3 stations top 2 CM only)		May										
Surface grabs for chemistry, 7 stations on project site (top 2 cm)		May	August			August						August
Surface grabs to document taxonomy prior to project work 2 stations	X											
Surface grabs for taxonomy: 2 stations on enhanced natural recovery area		August	August			August						August
2 stations on 3' cap		August	August			August						August
REMOTS camera survey		August	August			August						August
Monitoring report for given year (due January of following year)		X	X			X						X
Monitoring review meetings		X	X			X						X
Four year project review												X

NOTES:

- a) Baseline sampling will be conducted as soon as practical within the first three months after cap placement.
- b) Monitoring review meetings may be held within the first two months of subsequent year.
- c) *Decision to sample in 2002 will be based on meeting in 1998.
- d) Sampling targeted for August may also be completed in September, if necessary.

LEGEND

- ⊗ Bottom Stake
- ← Stake Number
- 3/28 Cap Depth in Feet
- Coring Station
- ▣ Grab Sample Site (Chem only)
- Grab Samples (Chem & Taxonomy)
- Water Depth in Feet at MLLW
- ▨ 1Ft Enhanced Natural Recovery Area.
- ▩ 3 Ft Cap

Scale: 1"=100'

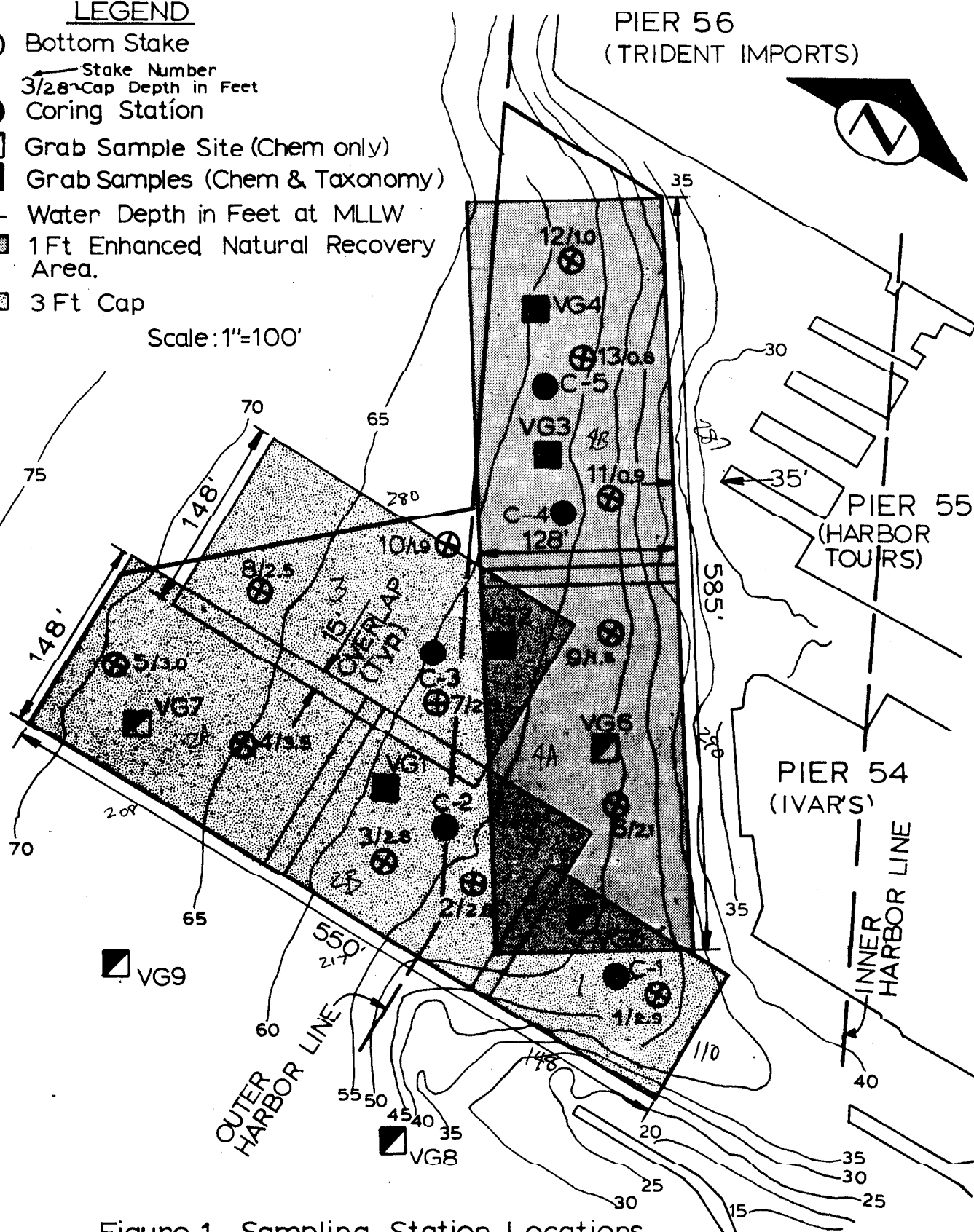


Figure 1. Sampling Station Locations
(also showing location of barge passes)

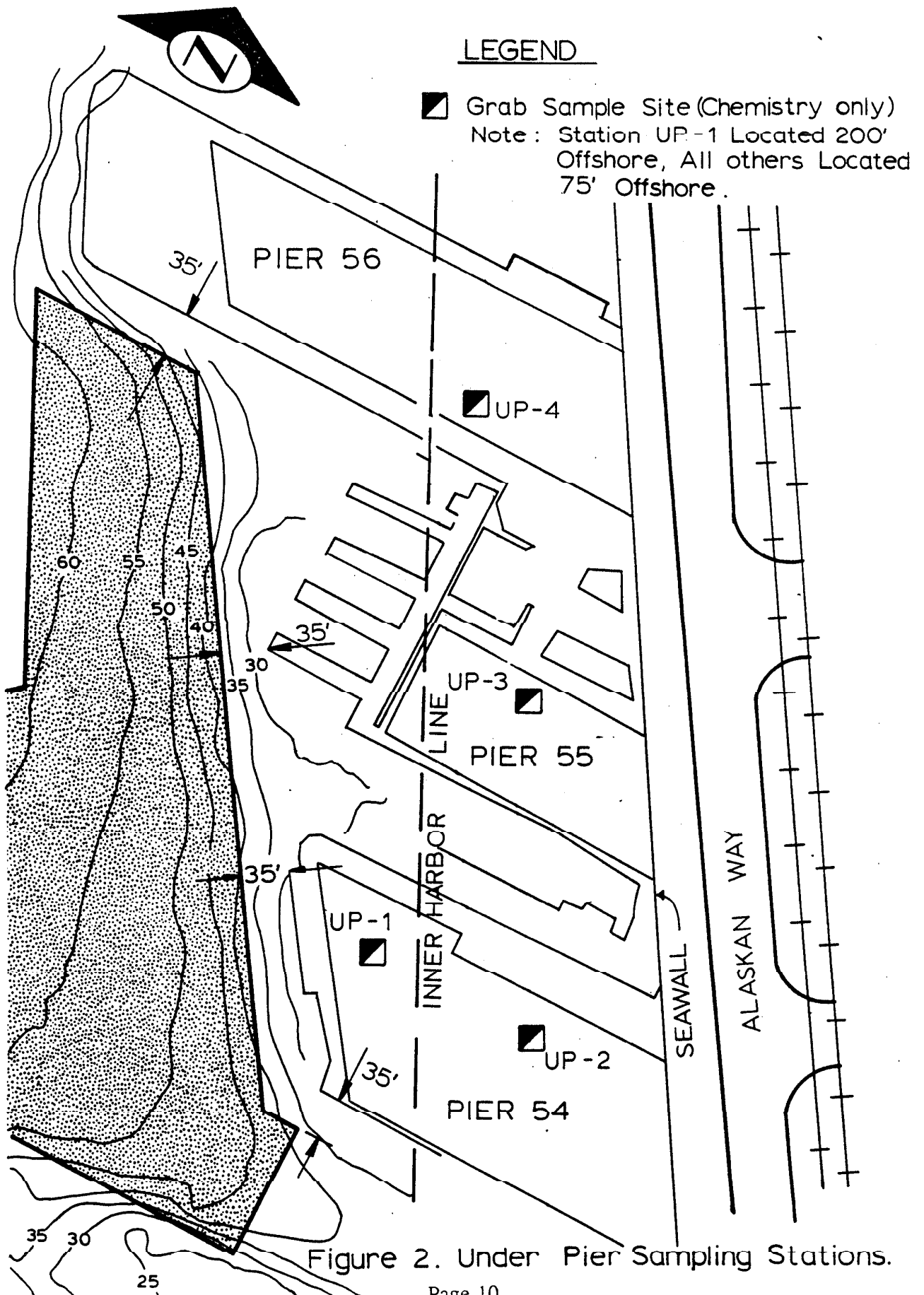


Figure 2. Under Pier Sampling Stations.

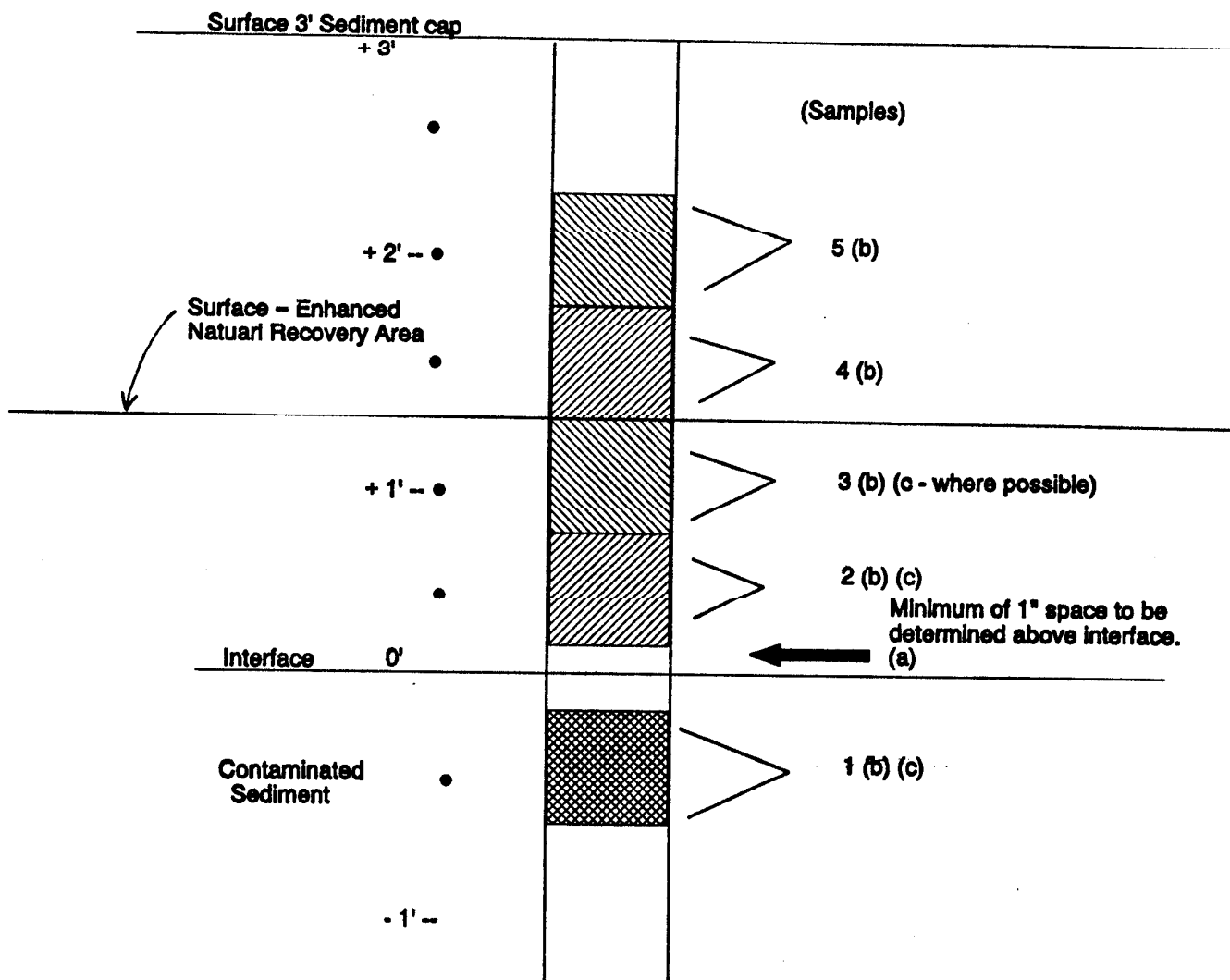


Figure 3. Cross section of sediment core showing the sections that will be taken for chemical analysis.

- (a) Determine based on degree of mixing apparent at the interface.
- (b) Section taken on 3' sediment cap.
- (c) Section taken on enhanced natural recovery area.

Table 2

MONITORING REPORT OUTLINE

Section 1: Background

Provide information on when and how the sediments were placed, including amount of sediment used.

List permits and licenses obtained and existing permit conditions.

Section 2: Placement and Thickness of Sediment Cap and Enhanced Natural Recovery Area

Provide map showing position and thickness of sediment cap and enhanced natural recovery area as determined by barge dumping records.

Provide a corrected map of thickness of sediment cap and of enhanced natural recovery area based on data bottom stakes and sediment cores.

Compare each subsequent survey with the previous survey and discuss whether the sediment cap and enhanced natural recovery area appear to be remaining stable.

Section 3: Isolation of Contaminants

Chemical data from baseline cores will be presented in tables and discussed regarding the following:

- Identify exact sampling locations on project site.
- Identify presence of chemicals in both the underlying sediments and "capping" material.
- Compare observed chemistry to the turning basin pre-dredged data.
- Check uniformity of chemistry between core sections.
- Display profile plots of representative chemicals.

Subsequent core data will be added to the tables to allow comparisons and then discussed regarding the following:

- Identify apparent chemical increases in both the sediment cap and the enhanced natural recovery area.
- Compare to chemicals in underlying sediments.
- Display profile plots of representative chemicals.

- If chemical levels in the sediment cap and/or the enhanced natural recovery area become significantly elevated, these values will be compared to Washington State Sediment Standards.

Section 4: Surface Contamination of Project Site and Adjacent Property

Chemistry data from baseline surface grab samples will be presented in tables and discussed regarding the following:

- Identify exact sampling location on project site and adjacent property.
- Identify chemicals present on project site and adjacent property.
- Compare surface chemistry on project site to turning basin pre-dredge data and to new core data from project site.
- Identify spatial differences in concentrations on project site.
- Provide data from adjacent property to Ecology for comparison to other locations on the Seattle waterfront (1992 report only).

Subsequent surface chemistry data will be added to the tables to allow comparisons and discussed regarding the following:

- Identify chemicals that appear to increase.
- Display plots of representative chemicals showing change over time.
- Identify spatial differences and implication to possible sources.
- If chemicals show a trend of significantly increasing concentrations, conditions on adjacent property will be evaluated as a potential source of contaminants.
- If chemical levels in the sediment cap or in the area of enhanced natural recovery become significantly elevated, the values will be compared to available Puget Sound Sediment Standards.

Section 5: Benthic Recolonization

Detailed taxonomy data will be presented in tables and discussed regarding the following:

- Identify exact sampling location on cap.
- Develop summary data regarding number of taxa and biomass.
- Display plots showing changes over time in number of taxa biomass.
- Compare the population resulting in the sediment cap and the enhanced natural recovery area after five years to populations found in similar type habitats as determined from previously collected data or a recent sample from an appropriate reference area.
- Compare the recolonization on the sediment cap and on the enhanced natural recovery area.

Section 6: Conclusions

- Regarding stability of the three foot sediment cap and of the enhanced natural recovery area.
- Regarding isolation of contaminants on the three foot sediment cap and on the enhanced natural recovery area.
- Regarding contamination of surface of the three foot sediment cap and of the enhanced natural recovery area.
- Regarding status of benthic recolonization of the three foot sediment cap and the enhanced natural recovery area.
- Regarding recommendations for future actions.